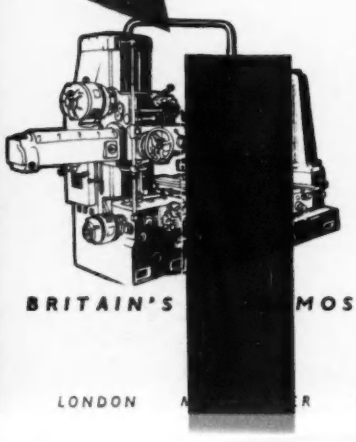
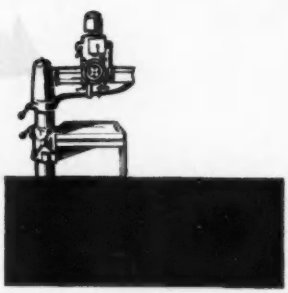
The
ENGINEERS' DIGEST

A World Review of
DESIGN & PRODUCTION · RESEARCH & DEVELOPMENT

VOL. XXII No. 8 AUGUST, 1961

MACHINE TOOLS





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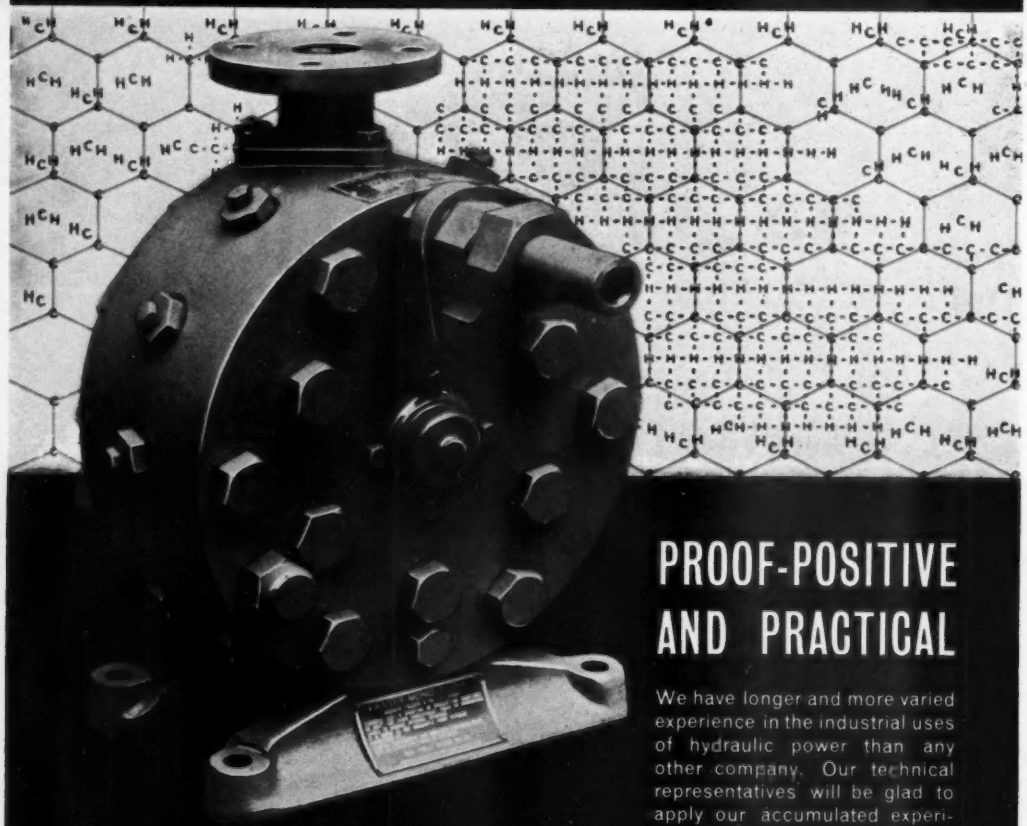

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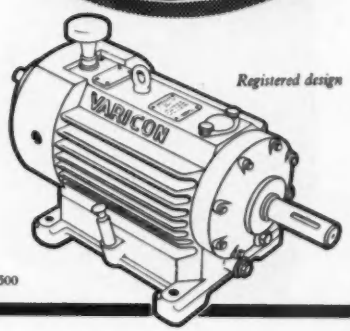

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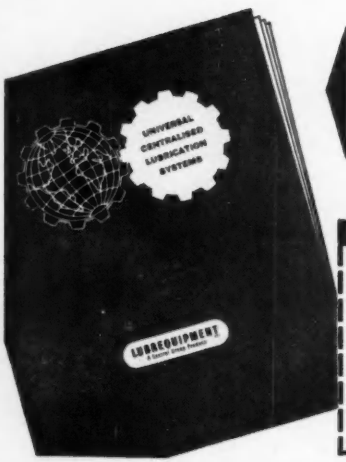

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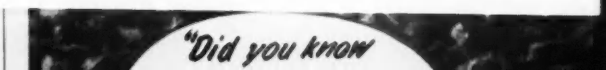

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The ENGINEERS' DIGEST

A World Review of DESIGN & PRODUCTION · RESEARCH & DEVELOPMENT

VOL. XXII No. 8 AUGUST, 1961

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The MINIDIGEST

By using an exhaust nozzle with a series of curved ridges and grooves along its inner cone, a recently patented system is said to show promise as a means of **reducing the noise of jet engines.** When the jet gases pass through the nozzle, they are broken up into numerous small air streams which flow along the ridges and grooves and mix together when they reach the open air. The result is stated to be a reduction in noise level with only a very small loss of thrust. The patent rights have been assigned to the Rohr Aircraft Corporation.

* * *

As reported in *Electrotechnicky Obzor* for June 1961, a **new design of compensated permeameter,** developed in Czechoslovakia, is eminently suitable for measuring the magnetic properties of ferromagnetic strip materials and has a quicker response than conventional permeameters, as well as being less sensitive to ambient vibration. In the new permeameter, which has a measuring accuracy within 2 to 3%, the compensation current is utilized for direct measurement of the magnetic flux without the use of a ballistic galvanometer. Acceleration of measurements can be achieved in a simple way by providing for automatic compensation; in addition, hysteresis curves can be obtained automatically by connecting the permeameter to a co-ordinate recorder.

* * *

As reported in *Siemens Zeitschrift* for June 1961, an investigation has been carried out to determine the recurrence rate of **self-healing punctures in metallized-paper capacitors** of different types under d.c. voltages. Some of the capacitors tested had already passed through all stages of production, while others had never before been subjected to any voltage at all. Mathematical relationships made it possible to make long-term predictions which were checked by appropriate tests, and it was found that it is reasonable to expect from two to seven self-healing punctures over a period of twenty years. The deterioration in capacitance as a result of self-healing is stated to be negligible in all cases.

* * *

As described in *Slevarenstvi* for June 1961, a process for **producing aluminium-alloy castings under low pressure** has been developed in Czechoslovakia. In this process, the alloy is

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heated in an electric resistance furnace to about 700 to 740°C and is then forced upwards (by applying an air pressure of about 3 to 7 psi to the free surface of the molten metal) via a tube into a metallic mould preheated to 150°C and located above the furnace. It is claimed that experiments with this process have shown that it is possible to obtain aluminium-alloy castings which are free from defects and which have a uniform fine-grain structure and good mechanical properties. In addition, it is stated that the process easily lends itself to automatic operation.

* * *

As described in *Machine Design* for June 8, 1961, the principle of a new **high-speed developing machine for motion-picture film** is the use of viscous chemicals which are squeezed onto the film like extruded toothpaste. A hopper pinches out the developing chemicals in a downward direction on the upward-moving film, applying a thin and even layer, only 0·008 in. in thickness, thereby reducing waste to a minimum. After developing, the film is rinsed in a jet of water and air-dried, after which the process is repeated with the fixing chemical. The total time for developing 36 ft of film is stated to be 1 min.

* * *

The higher is the temperature in a thermionic diode, the greater is the flow of electrons and, assuming that the problem of space-charge limitation can be overcome, the higher is the efficiency. According to a note in *Electronics* for June 23, 1961, a novel approach to the solution of this problem of space-charge limitation is under consideration and involves the **use of fissionable material for diode emitters.** The proposed use of fissionable material would provide not only a source of heat for the emitter, but also a source of radiation which would produce positive ions to negate the space charge. It is envisaged that the use of such a material would most probably find its main application in space-vehicle and other non-commercial systems.

* * *

Details of the results of investigations into the measurement of **radial forces and their influence on the cutting action of twist-drills** are reported in the Swiss journal *Microtecnic*, for April 1961. In this investigation, which is being carried out in Germany at the Technische

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These peaks have been well described as "the mountains of eternal light".

This little inset shows you how to find them with a strong pair of binoculars. The best time is when the Moon is a crescent in the Western sky. So lofty are these mountains that it is possible to see the peaks twinkling like stars in the darkened portion.

In this representation we show them as they would look in an eclipse when the Earth comes between the Moon and the Sun and the mountains take on a copper hue.

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The MINIDIGEST

Hochschule Braunschweig, torque, drill thrust, and radial force have been determined as functions of various factors, and include the relationship between radial forces and hole oversize caused by non-symmetrical drill-point geometry. It has been found that the rotary radial force is proportional to the percentage oversize of the hole. The factor of proportionality, defined as the specific radial force, is a radial force whose action causes an oversize of 1% of the nominal diameter. The radial force acting when drilling with twist-drills can be used as a criterion of the quality of the drilling operation.

* * *

It is reported in the *Review of the Electrical Communication Laboratory* (No. 1-2, 1961 of the Nippon Telegraph and Telephone Public Corporation that a **silver-bonded diode for use in parametric amplifiers,** developed in Japan, has outstanding characteristics. The diode is constructed by bringing the tip of a silver whisker containing gallium into contact with an *n*-type germanium wafer of from about 0·02 to 0·2 ohm resistivity, and then electrically forming the junction. This diode is claimed to have a series resistance of less than 10 ohms, a barrier capacitance of less than 0·3 pF, and a cut-off frequency of more than 200,000 Mcs. In addition, it is stated that these characteristics do not deteriorate at temperatures as low as −170°C.

* * *

It is reported in *Product Engineering* for June 26, 1961, that a **new superconducting alloy for use at cryogenic temperatures** has been developed by the Atomics International Division of North American Aviation. The alloy, which is a cold-worked material containing about three parts of niobium and one part of zirconium, is stated to be malleable and strong, and can be worked into bars, strips, and other shapes without losing its superconducting properties. It is expected to retain these characteristics in high magnetic fields, making it possible to produce superconductor magnets without iron cores, in place of comparatively bulky and inefficient conventional iron-core magnets. A wire, capable of being coiled easily, has apparently already been drawn from the new alloy and is stated to have conducted 100,000 A/cm^2 at a temperature of −452°F in a magnetic field of 300,000 gauss.

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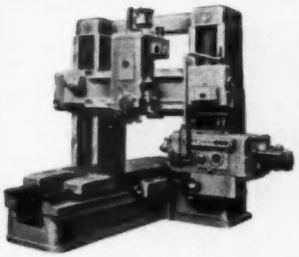

Maschinenfabrik Hermann Kolb, Cologne, Germany.
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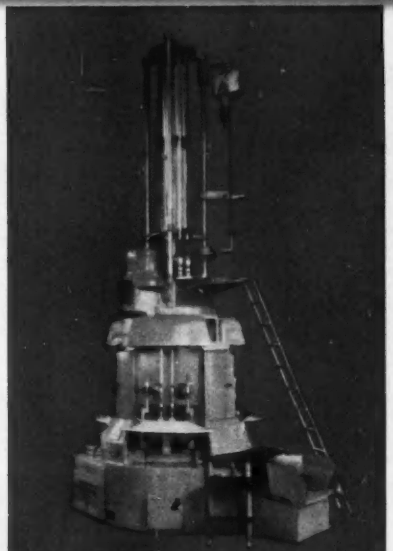
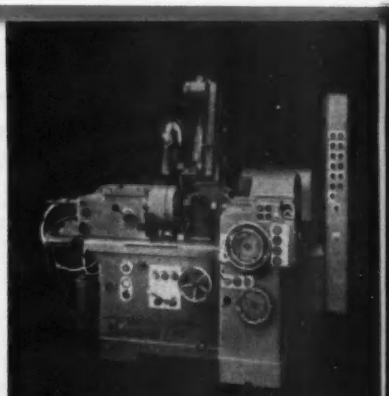


Hall 2 Stand 2104.



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Internal And/Or Face Grinders, Duplex Internal Grinders, Centre Grinders.

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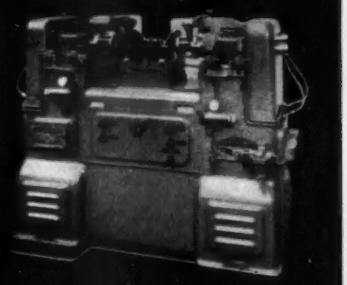

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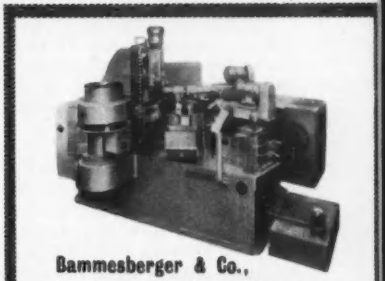

Bammesberger & Co., Leonberg, Stuttgart, Germany.
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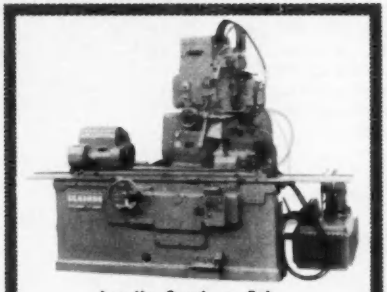

Landis Gendron S.A., Villeurbanne, France.
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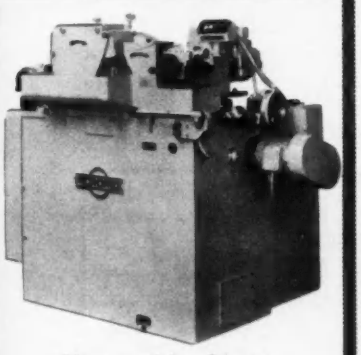

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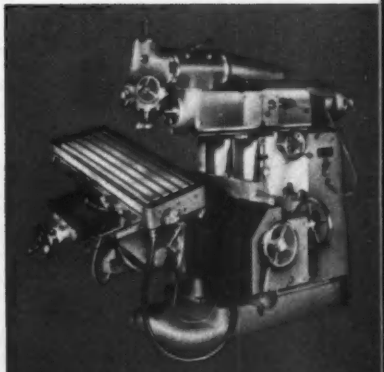

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BUSINESS NOTES

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* * *

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* * *

An agreement has been concluded between **Flexibox Ltd.**, of Manchester, and **Alfred Herbert Ltd.**, of Coventry, under the terms of which the latter company are appointed sole agents for the sale of the Flexibox range of lapping machines.

* * *

The Drayton Regulator & Instrument Co. Ltd., of Bridge Works, West Drayton, Middlesex, announce that the name of the company has been changed to **Drayton Controls Ltd.** The telephone number remains unchanged, i.e., West Drayton 4012, but the telegraphic address has been altered to Draycon West Drayton Telex.

* * *

The London offices of **Crofts (Engineers) Ltd.** have moved from 34 Norfolk Street, London, W.C.2, to new premises at 36/42 Tanner Street, Bermondsey, London, S.E.1 (Tel: HOP 7751/4).

* * *

P.M.T. (Machine Tools) Ltd., of Oozells Street, Birmingham 1, have been appointed exclusive distributors for **S.A.I.M.P.**, of Italy, manufacturers of precision lathes and milling machines.

* * *

It is announced by **Johnson, Matthey & Co. Ltd,** of 73-83 Hatton Garden, London, E.C.1, that they are now able to supply scandium, yttrium, and most of the fourteen rare-earth metals in sheet form in thicknesses down to 0·001 in. and with a maximum width of 3 in., either cold-worked or annealed. In addition, they are now producing zone-refined tellurium of high purity, the total metallic impurity content, excluding selenium, being less than 5 ppm and normally in the region of 1 ppm, while the selenium content does not exceed 5 ppm. This tellurium is supplied as half-round bars measuring approximately 1 × ½ in.

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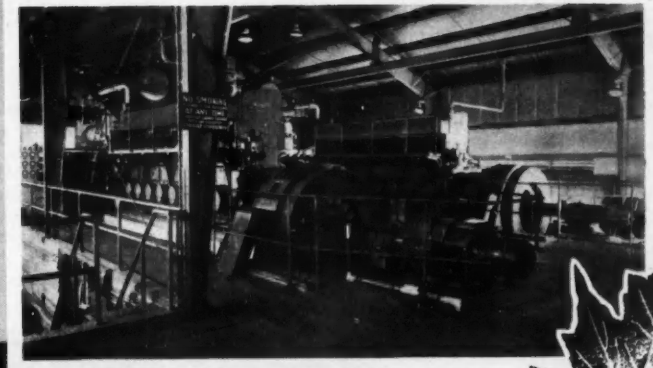

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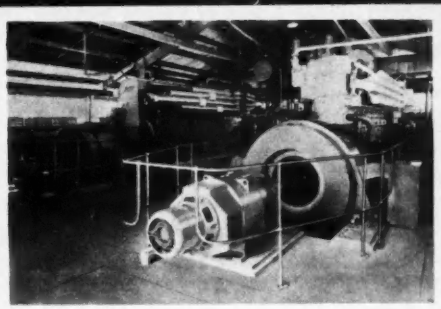

turbo-charged dual fuel engined installation operating on natural gas in EASTERN CANADA

The Gananoque Electric Light and Power Company, Limited, Ontario, have commissioned a new Power Station to meet the increasing demands of the Township. The Generating Plant of the Station which is shown above consists of two—Mirrlees KSP 8 Dual Fuel Engines direct coupled to Brush Alternators each having a continuous rating of 1360 kW 450 r.p.m. The Mirrlees KSP and KVSP Dual Fuel Range comprises 3, 5, 6, 7 and 8 cylinder engines in line and 12 and 16 cylinder engines in vee form developing powers up to 3850 b.h.p. continuously at 450 r.p.m.

Our Overseas Associated Company in this territory is Orenda Industrial Limited, Rexdale, Canada.

Mirrlees engines

MIRRLEES, BICKERTON & DAY LIMITED
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BUSINESS NOTES

manufacture under licence the Model EHP hydraulic speed governor being produced by **Curtiss-Wright Europa N.V.** in Leiden, Holland. Under the agreement, the Leiden factory will operate under the name of **Regulateurs Europa N.V.** as Ardleigh's subsidiary company and will continue to make and sell the EHP governor as before.

* * *

It is announced by **The Press & Shear Machinery Co. Ltd.,** of 172/178 Victoria Road, Acton, London, W.3, that they have been appointed exclusive distributors in the U.K. of the well-known double-crank power presses manufactured in France by **Hubert-Juy-Legros,** of Paris. These patented presses not only ensure fulfilment of the ideal operating conditions of the lowest possible velocity of the ram at the point of impact and constant speed of the ram during the working stroke, but also retain the feature of rapid operation possessed by standard presses.

* * *

Aveley Electric Ltd., of Ayron Road, Aveley Industrial Estate, South Ockendon, Essex, announce that they have been appointed sole U.K. agents for the **Hudson Tool & Die Co. Inc.,** of Newark, N.J., the largest manufacturers in the U.S.A. of drawn and pressed metal enclosures for electronic components, over 1600 different standard cans being available on stock or short delivery.

* * *

The London offices of **Rhodes, Brydon, Youatt Ltd.,** have been moved from 76 Victoria Street, London, S.W.1, to new premises at 45/51 Leman Street, London, E.1 (Tel: ROYal 1212).

* * *

A licence agreement has been signed between **C. A. Parsons & Co. Ltd.,** of Newcastle-upon-Tyne, and **Zallea Brothers,** of Delaware, U.S.A., for the manufacture and sale of a range of thinwall-bellows expansion joints of Zallea design, these joints being used to absorb movement in a wide range of piping applications, particularly in the oil and chemical industries. The agreement provides for the marketing of the British-made products in the U.K., the European Free Trade Area, and the British Commonwealth, with the exception of Canada.

* * *

It is announced that the **Stedall Machine Tool Co.** have been appointed distributors by **Impregnated Diamond Products Ltd.** of the latter company's range of "Sparcatron" spark-erosion machines, and of their "Sparcard" tungsten carbide impregnating machines for cutters, lathe tools, etc.

* * *

The **General Electric Co. Ltd. of England** and **Thompson Ramo Wooldridge Inc.,** of Los Angeles, Cal., U.S.A., have formed a new joint British company, with headquarters in London, to market industrial process-control systems in the U.K., the European Free Trade Area, and the British Commonwealth. The new company, **International Systems Control Ltd.,** will start with a capital of £430,000, equally shared by the parent companies.

* * *

The head sales office of **Whitehouse Industries Ltd.,** manufacturers of "Philidas" self-locking nuts and fixings, has been transferred to new premises at the company's works at Monkhill, Pontefract, Yorks. (Tel: Pontefract 2011/2/3; telegraphic address: "Philidas Pontefract"; Telex No. 55166). Remittances and accounts matters should, however, continue to be addressed to the company's Accounts Department, Ferrybridge, Knottingley, Yorks.

* * *

Following an agreement signed with the patent holders, **NSU Motorenwerke A.G.** and **Wankel G.m.b.H.,** it is announced that **F. Perkins Ltd.,** of Peterborough, will manufacture NSU Wankel petrol marine engines and diesel engines in the U.K.

* * *

Petbow Ltd., of Sandwich, Kent, have taken over the Liverpool factory of **Vernons Industries Ltd.,** together with all the manufacturing rights on their range of aircraft ground-starting and servicing equipment, high-frequency alternators, converters, etc. The combined factories will now enable Petbow Ltd. to offer the most comprehensive range of equipment of this type in the world.

CHAPMAN & HALL

announce that in association with
REINHOLD PUBLISHING CORPORATION
they can supply the following books from
ENGINEERING PUBLISHERS—NEW YORK

Retma Symposium on Reliable Applications of Electron Tubes 1956. (40s.)

Second Retma Conference on Reliable Electrical Connections 1956. (40s.)

Retma Symposia on Applied Reliability 1956 and 1957. (40s. each)

EIA Conference on Maintainability of Electronic Equipment 1957. (40s.)

EIA Symposium on Numerical Control Systems for Machine Tools 1957. (40s.)

Electron Tube Life Factors (76s.)

EIA Conference on Value Engineering 1959. (48s.)

Electronics Components Conference Proceedings 1958. (48s.)

EIA Conference on Automation Systems for Business and Industry 1958. (48s.)

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CONTRACTS

A contract to the value of about £100,000 has been signed by the Iraqi Port Authority and Pye Telecommunications Ltd., of Cambridge, for the supply and installation of a v.h.f. and u.h.f. radiotelephone network, comprising v.h.f. telephone services at Margil for Basrah airport, the port ambulance, fire-fighting units, the electricity distribution department, and the maritime services, as well as four other v.h.f. communication systems for the maritime services at Al-Wasillah, Fao, the deep-water berth, and Um Qasir. In addition, a u.h.f. telephone link will be installed between Fao and the deep-water berth, as well as a v.h.f. telephone service aboard the port's maritime vessels. It is anticipated that the entire scheme will be fully operational in 1962 and that it will be one of the most modern in the whole of the Middle East.

* * *

W. & T. Avery Ltd., of Birmingham, have recently obtained an order worth more than $115,000 from the National Harbours Board of Canada for three automatic grain weighers. These weighers will be by far the largest purely gravity-operated machines of this type ever made, having a capacity of 20,000 lb for each weighing, with each scale capable of handling up to 40,000 bushels per hour. Another feature of these weighers is their high accuracy, the maximum error being less than 0·02%, taken over a run of twenty consecutive weighings. Also, their maintenance is negligible, as their design is simple and robust, while no external services are required, apart from electrical power when actually testing and weighing residue.

* * *

Following the recent order for four complete sets of condensing and feed-heating plant of entirely new design for the Tilbury "B" power station, the Richardsons Westgarth Group have received a further order, valued at about £300,000, from the Central Electricity Generating Board, for condensing plant to be used with a 300-MW turbo-generator at West Thurrock power station.

* * *

An order, valued at about £500,000, has been received by Richardsons, Westgarth & Co. Ltd., of Wallsend, Northumberland, from the Government of Curacao for two vacuum flash evaporators, each capable of producing 1,400,000 gallons of drinking water per day. As such, these units will have a larger individual output than any evaporator so far built anywhere. The order is scheduled to be delivered in less than twelve months.

* * *

An order has been received by the Traction Division of Associated Electrical Industries Ltd. through AEI South Africa (Pty.) Ltd. for three 28-ton 500-V underground locomotives of 2-ft gauge for Goldfields of South Africa Ltd. These locomotives, which are scheduled for delivery in 1962, are of the double-bogie type, with both rheostatic and compressed-air braking, and will be driven by four force-ventilated traction motors supplied by a

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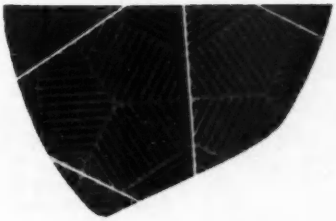
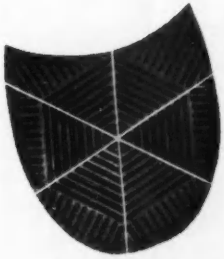
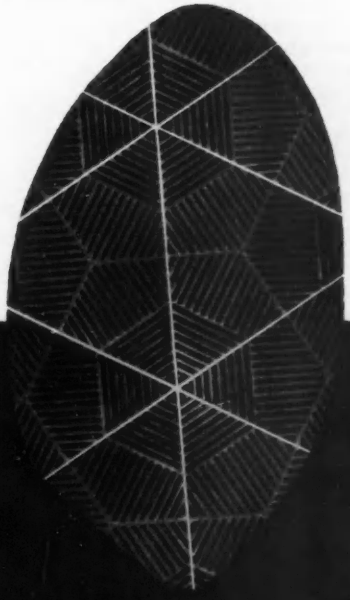


Basic steps to INDUSTRIAL SAFETY





In the shape of an equilateral triangle providing three point foundation which prevents rock and danger from projecting units, Tri-Pedal iron flooring is hygienic, dustless and will stand up to severe traffic conditions.
The flooring is impervious to water, oils, grease and acids generated in manufacturing processes and is unaffected by extremes of temperature.

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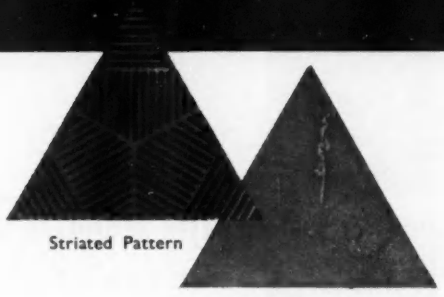
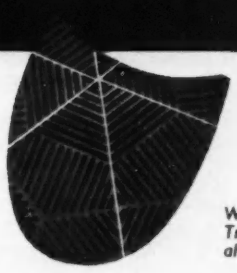


Striated Pattern



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TP. 22

CONTRACTS

pantograph. A triple combination of the motors will provide groupings of "all in series", "series/parallel in pairs", and "all in parallel". For control, electro-pneumatic contactors will be used, and automatic acceleration will be controlled by a current limit relay. Both driving cabs will be fitted with a shatterproof glass windscreen, a forward-facing driving seat, and a small cooling fan. A hotplate will also be provided.

* * *

A contract valued at more than £250,000 for the installation of a push-button mechanical parcel-sorting system at the new London Western District Office of the General Post Office has been awarded to Sovex Ltd., of Erith, Kent. This system will be similar to another system, also installed by Sovex, which has been operating successfully for more than 18 months at the Leeds parcel-sorting office. Twelve primary sorting positions will be provided, and the system, which incorporates more than a mile of conveyors, will be capable of handling up to 90,000 parcels per day.

* * *

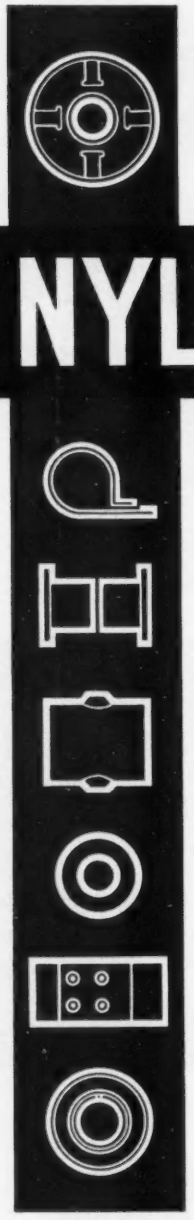
In the face of keen competition from Austrian and German firms, John Thompson (Dudley) Ltd. have obtained an order in Hungary for rotary coil-pickling plant and acid-recovery equipment, scheduled for operation towards the end of 1961. The pickling plant is capable of handling from 16 to 17 tons of material per hour, entailing the pickling, rinsing, neutralizing, and oiling of coils of wire, of from 2 to 5 mm thickness, in coils of 1200 mm o.d. and 500 mm i.d., varying in width from 200 to 350 mm. The acid-recovery plant is of the shock-cooling type and is designed to treat the waste acid from the pickling plant, the recovered acid being returned to the pickling plant by means of a continuous flow system. In addition to effecting a considerable saving in the running costs of the pickling plant, the acid-recovery plant ensures a maximum output by enabling a constant tonnage to be maintained.

* * *

An order worth approximately £125,000 has recently been received by the General Electric Company of England for a materials-handling plant with a maximum unloading capacity of 2000 tons per hour, to be installed in a self-unloading ship. The order was received from William Hamilton and Co. Ltd., of Glasgow, who are building the vessel for North American owners, who will operate it in Canadian waters.

* * *

Napier Aero Engines Ltd., the new company formed a month ago by D. Napier & Son Ltd. and Rolls-Royce Ltd., has received an order, estimated to be worth £1,200,000, from the Australian Government for the supply of "Gazelle" free-turbine engines for powering 27 Westland "Wessex" Mk.31 helicopters, together with spares and support equipment. This type of engine is the same as that used in the "Wessex" helicopters currently in service with the Royal Navy and in the "Belvederes" in service with the R.A.F.



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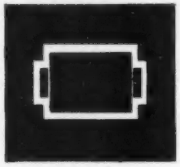

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PERSONAL

It is announced by The United Steel Companies Ltd. that **Mr. F. Holloway** has now become secretary and office manager of their Workington Iron and Steel Company branch, following the retirement of **Mr. W. McGregor.** In addition, **Mr. G. Hird** has been appointed agent responsible for the company's mining and quarrying properties in Cumberland, following the retirement of **Mr. J. S. Booth.**

* * *

Mr. J. E. C. Bailey, C.B.E., M.I.Ex., has been appointed to the board of Derbyshire Stone Ltd. Mr. Bailey will continue his executive duties in the Baird & Tatlock Group as chairman and managing director of each of the operating companies in the Group, comprising Baird & Tatlock (London) Ltd., Hopkin & Williams Ltd., and W. B. Nicholson (Scientific Instruments) Ltd., all members of the Derbyshire Stone Group of companies.

* * *

Mr. H. R. Brooker has joined the board of Johnson, Matthey & Co., Ltd., of London, E.C.1, as a joint managing director of the company.

* * *

It is announced that **Mr. E. M. Heap,** joint managing director of York Shipley Ltd., refrigeration engineers, of London, N.W.2, has been appointed to the board of Le Froid Industriel Brissonneau-York, S.A., of Paris.

* * *

Hilger & Watts Ltd. announce that **Mr. A. H. Campbell, M.A., M.I.E.E.,** who has been a director of the company since 1951 and general manager since 1954, has been appointed joint managing director with **Mr. G. A. Whipple, M.A., M.I.E.E., F.Inst.P.**

* * *

The British Steel Castings Research Association, of Sheffield, announce that **Mr. W. S. Scott M.A. (Cantab.),** managing director of The Darlington Forge Ltd., has been elected chairman of the council of the Association, in succession to **Dr. R. Hunter,** deputy managing director of The Clyde Alloy Steel Co. Ltd. **Dr. C. J. Dadswell,** managing director of The English Steel Castings Corporation, has succeeded Mr. Scott as vice-chairman of the council.

* * *

Mr. M. H. Gardiner, F.C.A., and **Mr. C. Phillips, M.I.Mech.E., M.I.Prod.E.,** have been appointed joint managing directors of Redman Tools & Products Ltd., of Gregory's Bank, Worcester. **Mr. A. M. Redman** retains the chairmanship and there is no change of control.

* * *

As announced by Babcock & Wilcox Ltd., **Lt.-General Sir William Stratton, K.C.B., C.V.O., C.B.E., D.S.O.,** has been appointed chairman of Edwin Danks & Co. (Oldbury) Ltd. and of Penman & Co. Ltd., both members of the Babcock & Wilcox Group, in succession to the late **General Sir Kenneth Crawford**. It is also

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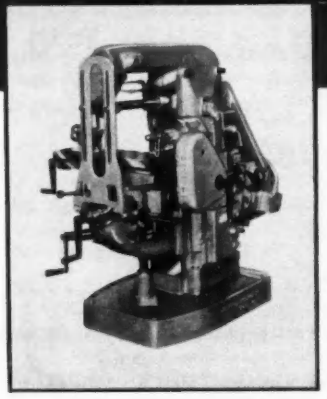

Illustrated above is the 03SD Richmond Universal Milling machine selected by General Electric Company Limited, from the extensive range of "RICHMOND" Milling and Drilling machines. Built from the finest materials and incorporating first-class workmanship, all "RICHMOND" machine tools are simple to set up, easy to adjust and combine high productivity with exceptional accuracy.

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THE 600 GROUP OF COMPANIES

PERSONAL

announced that **Sir Noel Hall, M.A.,** and **Mr. L. W. Cole, B.Com.,** have been elected directors of Babcock & Wilcox Ltd. Sir Noel was recently appointed Principal of Brasenose College, Oxford, and is a director of Fisons Ltd. Mr. Cole became secretary of Babcock & Wilcox in 1952 and was made responsible for financial control within the Group in 1958. He retains the position of secretary until December 31, 1961.

* * *

Sir Ben Lockspeiser, Mr. C. F. Hodson, and **Mr. W. H. West** have been appointed to the board of J. H. Shand Ltd., of Axminster, a member of the Staveley Group of companies.

* * *

Henry Simon (Holdings) Ltd. announce that **Mr. F. J. Sullivan,** previously commercial manager of Turbine Gears Ltd., has been appointed a director of the company.

* * *

Mr. J. L. Thompson, general manager and director of Square D Ltd., has been appointed managing director. **Mr. D. Gemmell, A.M.I.E.E.,** executive director, has been appointed general manager of the company's Swindon establishment, while **Mr. H. C. Camp,** sales manager, has been appointed executive director. Both Mr. Thompson and Mr. Camp will be based at the company's new executive headquarters in Park Lane, London, W.1.

* * *

It is announced by Hoover Ltd. that **Mr. J. C. Shapley,** works manager at the company's factory in Perivale, Middlesex, has been appointed to the board of Hoover (Electric Motors) Ltd., of Cambuslang, Lanarkshire.

* * *

Mr. A. A. Farrell, formerly general manager of Plessey Ireland Ltd., has been appointed director and general manager of Plessey Ireland Ltd., and also a director of Plessey Sales Ltd., Dublin.

* * *

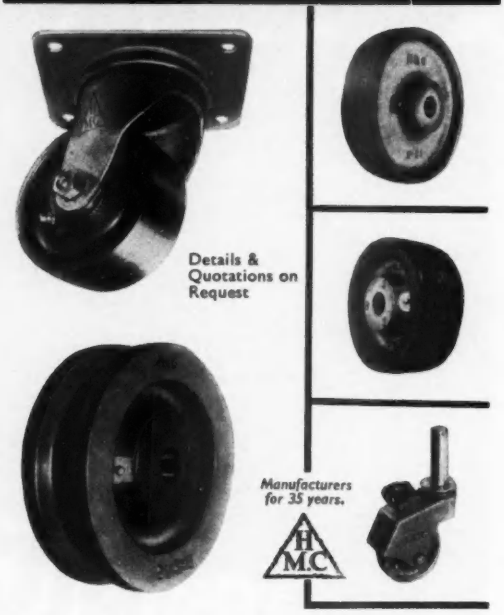
It is announced by the Midland Industries Group that **Mr. D. L. C. Rees** has been appointed financial director and **Mr. F. H. Hipkin** commercial director of the Boston Marine & General Engineering Co. Ltd., while **Mr. B. Robinson** has been appointed to the board of Bettles & Sons Ltd. Both these Wolverhampton companies are members of the Midland Industries Group.

* * *

MR. G. H. ALEXANDER

It is with deep regret that we announce the death, at the age of 95, of Mr. George H. Alexander, founder and director of George H. Alexander Machinery Ltd., of Birmingham.

WHEELS & CASTORS FOR INDUSTRY



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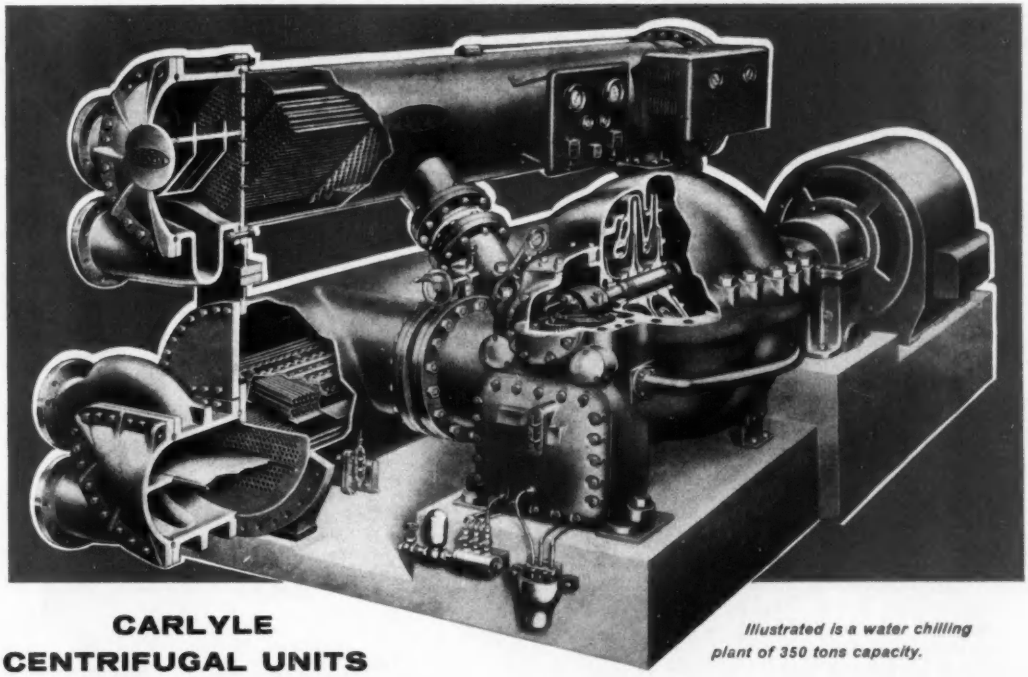

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NEWS ROUND-UP

The Cross-Channel Power Link

The new power link across the English Channel is an outstanding example of the closest co-operation between British and French national electricity undertakings and electrical manufacturers. It is also unique in that it will connect for the first time the integrated British electricity-supply network with the integrated Continental network. When completed, the link will permit the transfer between both countries of 160 MW of power from one system to the other at 200,000 V. d.c. and 800 A. This reserve of power, which will be on call when the link is commissioned later this year, is mutually available because of the very different periods (hourly, daily, and monthly) when the demand for electricity in France and Britain is greatest, and because of the different generating methods in use in these two countries. This ability of one country to call on the other for power means that Britain, at times of peak demand, will have available the power which would otherwise have had to be generated from additional plant installed in the U.K., at considerably greater expense than the British share of the cost of the cross-channel scheme. Costing over £600,000, the task of making and laying the British half of the twin power cables is being shared by Associated Electrical Industries Ltd. and by British Insulated Callender's Cables Ltd., the contract being awarded by the Central Electricity Generating Board in July 1960. The French half of the laying project has been carried out by companies appointed by the French national electricity undertaking, Electricité de France.

Direct current was chosen as the transferring medium between the 275-kV, 50-cps, a.c. British supergrid standard and the 225-kV 50-cps, a.c. French network because studies showed that the originally proposed a.c. link would have given rise to great difficulty in keeping the load transfer under control, as small frequency variations between the a.c. systems of the two countries would lead to overloading. Also, direct current has the additional advantage that more power can be transferred with the same thickness of insulation than is possible with alternating current, and is therefore more economical insofar as cable costs are concerned.

The cross-channel cable link, with its submarine and land connections, will be about 38 miles in length, and will connect converter stations at Lydd, in Kent, and at Echingen, just east of Boulogne. At Lydd, connection will be made to the British grid via a 275-kV line to Canterbury, while at Echingen 225-kV connections will go out to Amiens and Holque. The Lydd converter station is connected by an underground d.c. cable, from 3 to 4 miles in length, to a link-house at Dungeness, while the Echingen station is connected by land cable to the sea cable at Le Portel, a suburb of Boulogne.

The twin cables are laid sufficiently closely together to ensure that their magnetic field cannot deflect by more than 2 deg. the magnetic compass of any vessel on the surface. The cables, which have been laid side by side simultaneously at depths up to 180 ft, are of the impregnated paper-insulated solid type, each cable operating respectively at 100 kV positive and 100 kV negative to earth. The submarine-cable conductor is 0·525 sq in. in cross-section and consists of stranded copper wire lapped with an electrostatic screen. The solid-type

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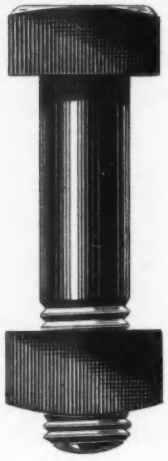

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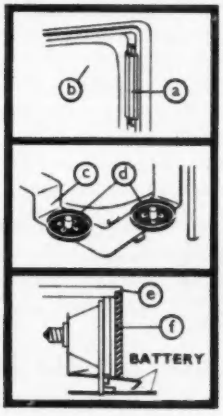

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impregnated-paper insulation, also lapped externally with an electroststic screen, is sheathed with a lead alloy protected against corrosion by vulcanized-rubber tapes.

Armouring is provided by a single layer of 0·232-in. galvanized steel wires with appropriate beddings and servings. The cables weigh about 39 lb per yard in air and about 28 lb per yard in sea-water. Anti-twist tapes are applied over the lead sheath and under the anti-corrosion protection to ensure that the cable will not be damaged under the excessive tensions that may be required to lift the cable out of the sand on the sea-bed during recovery after a possible fault.

Larger conductor sizes have been used for the land cables, because of the inferior heat-dissipating properties of the soil, compared with those of the sea. Over sections of the route where the normal type of loam is found, a conductor size of 0·6 sq in. is employed but, in the shingle areas, which have very poor thermal dissipation properties, a 0·925-sq in. conductor is necessary. The land cable is similar in design to the submarine cable, except that, over the Lydd-Dungeness link-house lengths, neither anti-twist tapes nor submarine anti-corrosion protection are used, and the armour wires are considerably smaller in size.

Expanded Production of Continuously Cast Rods and Tubes

Major plant extensions, enabling production to be doubled, have recently been completed at the factory of Enfield Rolling Mills Ltd. at Brimsdown, Enfield, Middlesex, in connection with the continuous casting of "Encon" phosphor-bronze and gunmetal rods and tubes. This increased production has also permitted a wider range of sizes and materials to be held in stock, enabling delivery to be made at short notice from over 1500 stock items. In addition, speedier delivery of special orders for non-stock items will be facilitated.

The continuous casting plant is similar to that developed by the American Smelting and Refining Company, from whom it is operated under licence. In principle, the method used is extremely simple, the virgin metals being melted, held in an atmosphere of nitrogen, and cast through graphite dies, the vertically cast bar passing through guide rollers on the floor below the die and cut off into lengths on a lower floor. The constituents of the alloy to be melted are weighed out into skips in wheeled bogies and are elevated to the top floor of the four-storey casting building. They are then tipped into a Birlec-Detroit rocking arc furnace of 500-lb capacity. When the melt is ready, the arc furnace is tipped hydraulically and the molten alloy is transferred to the charging box of the continuous casting furnace. This furnace is lined with refractory, and is heated by carbon resistors, a nitrogen atmosphere being maintained in the furnace to prevent oxidation of the melt. The graphite die is located in a water-cooling jacket at the base of a graphite crucible, a shut-off plug being provided to close the channel through which the molten metal flows to the die. The handle controlling this plug is on the casting floor below the furnace.

To start the casting operation, a starter bar is inserted into the underside of the die, and, with the furnace

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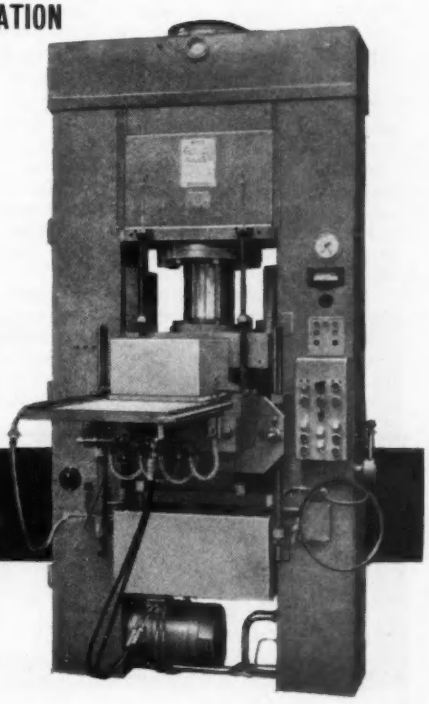

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shut-off plug in the open position, the starter bar is drawn steadily down by the roll mechanism on the casting floor. The speed of withdrawal is adjusted in such a way that the metal freezes as it passes through the cooled die. By the time the metal reaches the outlet of the die, it is sufficiently solid to support the mass of liquid metal above, and casting continues as long as the cooled metal is withdrawn at constant speed from the die. The starter bar is removed when the cast bar or tube emerges from the roll mechanism.

The newly cast bar or tube is cut into lengths by a horizontal resin-bonded abrasive wheel. The cutting-off unit, which is clamped onto the downward-moving stock, is counterpoised by a heavy weight or by hydraulic means and is aligned by rollers running on the faces of a vertical steel column of hexagonal cross-section. The cut section is received in a vertical tube which is pivoted so that the cut sections can be drawn out into a horizontal roller-type run-out table. The tube or rod is inspected and dimensionally checked on this table and, after straightening, is passed to stock or for despatch, as required.

New Engineering Laboratory for the British Welding Research Association

A new 21,000-sq ft engineering laboratory has recently been opened at the research station of the British Welding Research Association at Abington Hall Cambridge. Apart from research facilities in other, buildings, the new two-story building houses facilities for work in connection with pressure vessels, brittle fracture, and resistance welding, as well as an extensive machine shop, while the upper floor provides much-needed office accommodation and conference rooms.

Since the Association acquired Abington Hall in 1946, the research work now transferred was until now carried out in the former stables and in ex-army huts. Despite the difficulties of working under these conditions, the Association has been able to sustain a heavy programme of research and to deal with a very wide variety of industrial problems, ranging from the study of brittle fracture in heavy steel plate to the welding of catch-plates into cooked-meat cans. The need has now arisen, however, to initiate several new and important lines of research and to extend considerably their range of scientific and commercial equipment, if the demand for the Association's services is to be met fully over the next few years. For this reason, the new building not only provides proper facilities for carrying out specified lines of research, but also relieves congestion in the other laboratories, thereby permitting metallurgical research work in general to be expanded.

International Heating, Ventilating, and Air-Conditioning Exhibition

The first International Heating, Ventilating, and Air-Conditioning Exhibition, to be held at Olympia, London, between September 26 and October 6, 1961, is expected to be the greatest display of its kind ever to be held in Europe. Covering an area of more than 100,000 sq ft, and featuring the products of some 220 firms of international repute, the exhibition will show all aspects of heating, ventilating, and air conditioning, including industrial air-handling and treatment equipment, dust and fume collection, mechanical draught, process heating, cooling, and allied equipment and services.

During the exhibition, which is organized by Industrial Exhibitions Ltd., an International Conference on Heating, Ventilating, and Air Conditioning, will take place at Olympia between September 27 and October 4. This conference, which has been organized by the sponsoring body, The Institution of Heating and Ventilating Engineers, in conjunction with The Association of Heating, Ventilating, and Domestic Engineering Employers and the Heating and Ventilating Research Association, will cover three main themes, i.e., (1) administrative advances likely in the next ten years, (2) technical advances likely in the next ten years, and (3) the integrated design of architectural services for economy of building construction.

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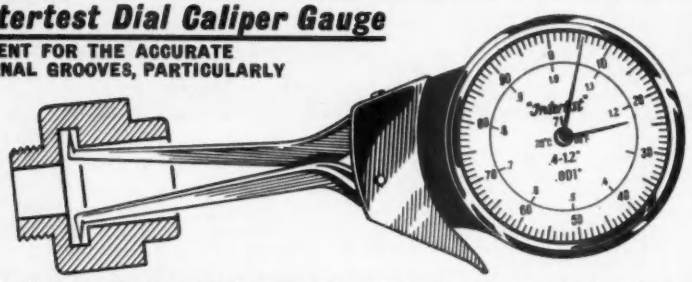

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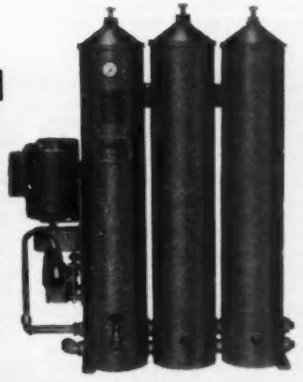

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NEW TECHNICAL BOOKS

Engineered Castings. By Glenn J. Cook. 266 pp., 125 illustrations. Publishers: McGraw-Hill Publishing Company Ltd., McGraw-Hill House, 95 Farringdon Street, London, E.C.4. Price: 66/–.

To all those interested in metal castings, this book will undoubtedly prove invaluable. Providing a wealth of practical data and facts on modern castings, including their inherent advantages and limitations, their present uses, and their future opportunities, this excellently produced volume gives fundamental technical information in simple form to aid in obtaining the best industrial results in the design, application, and purchase of engineered castings. The treatment is concise, yet lucid and comprehensive, and covers all important aspects of the field, such as types of castings and how they are made, the selection of metals, design factors, and purchasing standards and procedures, as well as considerable information of use to those interested in the sale of castings.

Tables of design features and costs give ready access to information on such factors as the choice of materials, complexity of parts, maximum and minimum sizes, mechanical properties, precision and tolerances, special structural characteristics, and surface detail and smoothness. In addition, they cover production requirements, rate of output, costs of raw materials, of tools and dies, of direct labour, and of finishing, optimum lot sizes, and other production essentials. Current advances in the industry are reported in detail, and clear discussions are given of the newer techniques in investment shell processes and induction stirring in arc furnaces, as well as up-to-date methods for the treatment of metals, shell-moulding, and ductile or nodular irons.

Introduction to Engineering Mechanics. By John V. Huddleston. 506 pp., 607 illustrations. Publishers. Adoison-Wesley Publishing Company, Inc., Reading Massachusetts, and 10-15 Chitty Street, London, W.1 Price: 74/–.

This interesting book, designed as a first course in engineering mechanics, emphasises the fundamentals of the subject, but differs from other introductory books on mechanics in its selection and sequence of topics. Thus, Dr. Huddleston, who is Assistant Professor of Civil Engineering at Yale University, has chosen to divide his subject on the basis of particles, rigid bodies, and deformable bodies, as opposed to the more traditional separation of statics and dynamics, in which little mention is made of deformable bodies.

By unifying statics, dynamics, and the strength of materials, students of electrical or chemical engineering can grasp the fundamentals of these subjects in a one-year course, instead of in the more usual two years. At the same time, students of civil engineering, mechanical engineering, metallurgy, or engineering science, who will continue the subject, are enabled to have sufficient background information to permit their study of more advanced topics in future courses. Although the book presupposes some knowledge of calculus and physics, it can be used successfully by students who have not yet taken a course in college physics and who are taking calculus concurrently. For such students, the elements of scalar calculus are included in an appendix. Another useful feature of the book is the inclusion of 120 solved examples and nearly 350 problems, judiciously selected to be as illustrative as possible. Many of these are "classical" problems in mechanics, but many new problems have been included.

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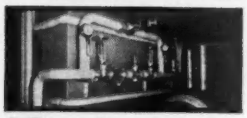

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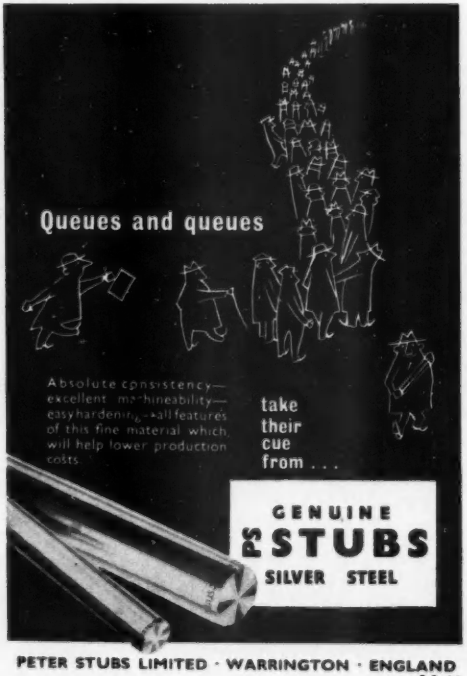
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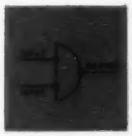

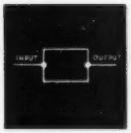

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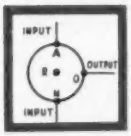

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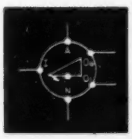

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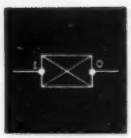

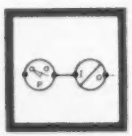

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Designed for applications in feed and clamping units of machine tools, welding, rolling, wood-working, diecasting, and paper-making machinery, mechanical handling and conveying equipment, etc., a range of hydraulic control systems is described in a 48-page brochure. A supplementary 20-page brochure contains details of design and operation of a range of pneumatic control systems comprising single- or twin-cylinder air compressors, single- or double-acting air cylinders, and a variety of pneumatic controls.

10. Rust Preventives

A selection of data sheets contains details of general-purpose and black dewatering rust preventives used for the protection of cylinder blocks, valves, bushes, camshafts, lathe carriers, driving pulleys, lineshafts, brake-shoes, flywheels, etc. Additional data sheets provide information on anti-corrosive materials, such as strippable coatings, anti-mist compounds, lanolin solutions, etc.

11. Lubrication Systems

Developed to meet the demand for higher pressures, variable control, and simple maintenance, a range of lubrication systems is described in an 8-page brochure. Layouts and design details of rotary-drive, back or front worm-drive, and ratchet-drive lubricators are given, and operation of the pump units and actuator assemblies is also dealt with.

12. Engineering Resins

An illustrated 8-page brochure contains information on the properties, methods of processing, and fabrication of a range of acetal, nylon, polyethylene, and acrylic resins, applications of which include bearings, turbine wheels, pump bodies, switches, cams and gears, electronic components. and a wide variety of machined parts.

13. Fluid-Power Equipment

The range of fluid-power equipment described in a 16-page brochure includes variable- and constant-delivery pumps, gear reducers, variable-speed transmissions, valves, and cylinders. In addition, a range of servo components, such as power amplifiers, pre-set units, servo valves and control assemblies, is included.

LITERATURE REVIEWED RECENTLY

14. Socket Screws

15. Cast-to-Form Tools

16. Zinc-Coated Steel Sheets and Plate

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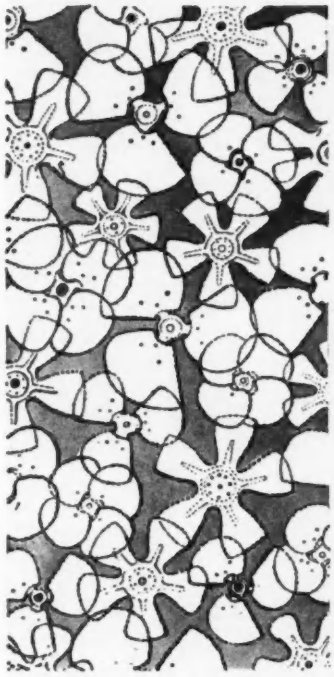

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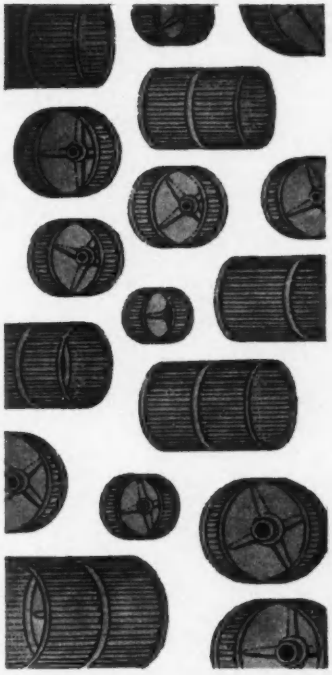

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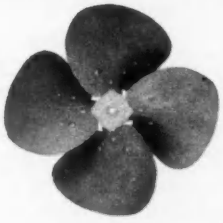

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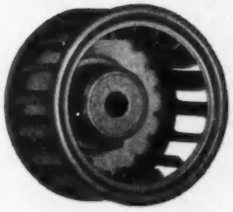

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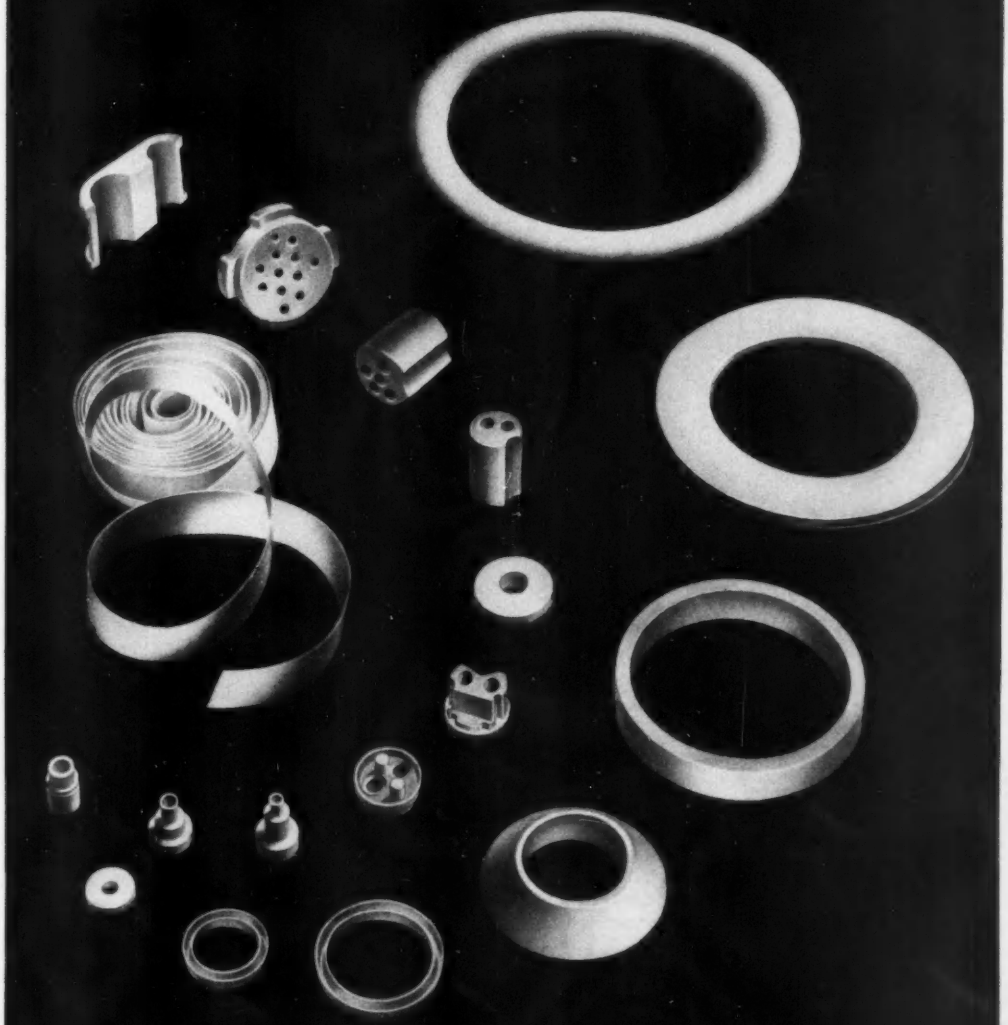

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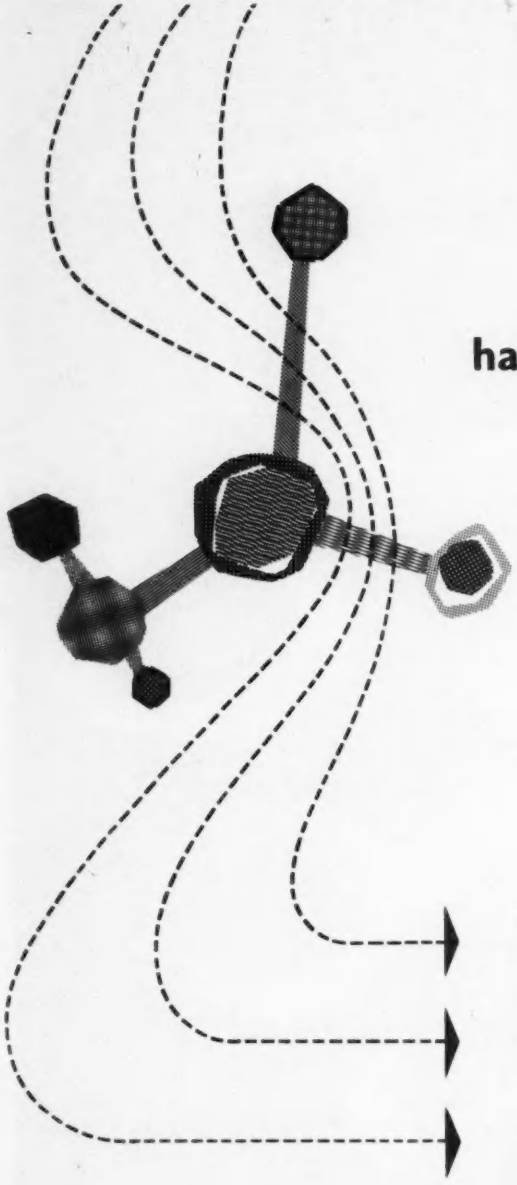

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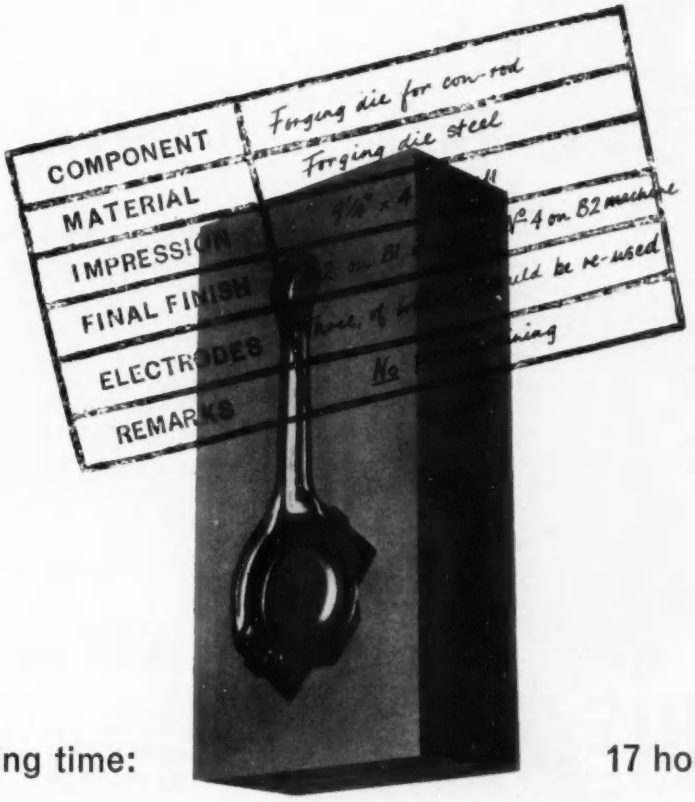

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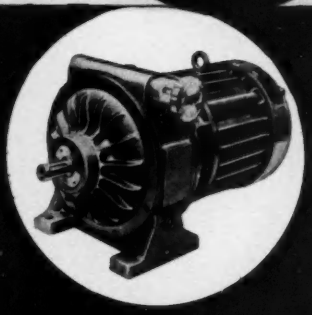

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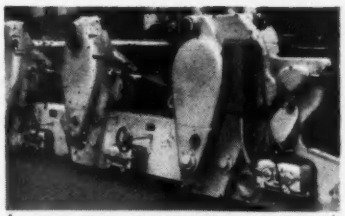

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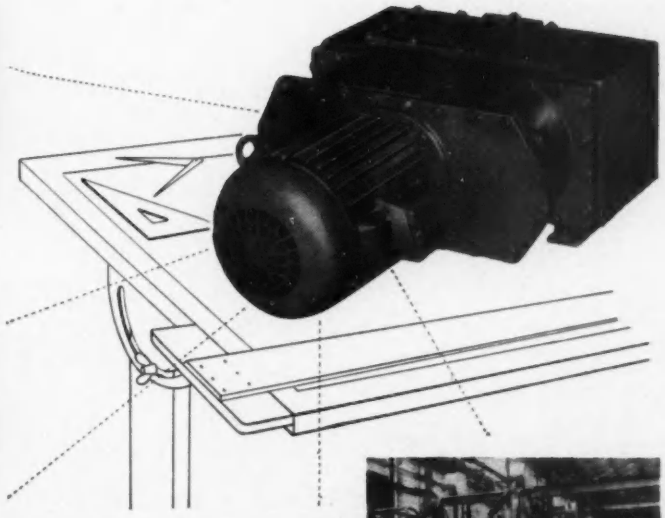

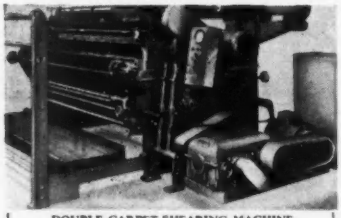

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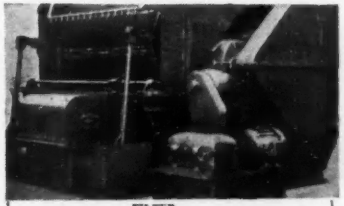

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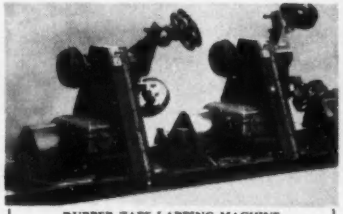

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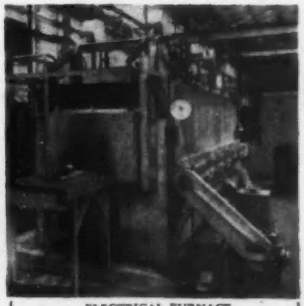

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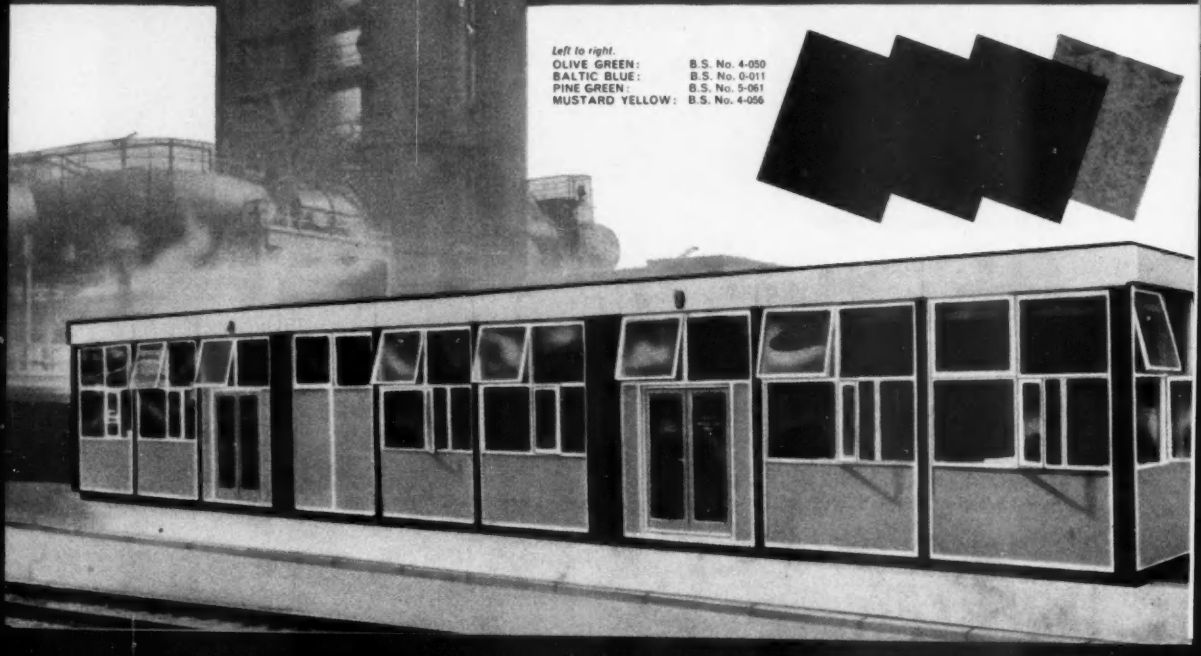

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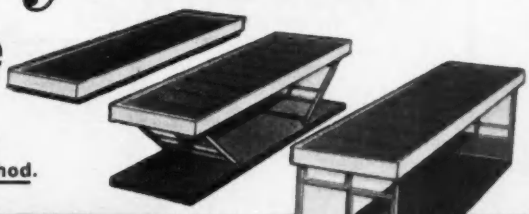

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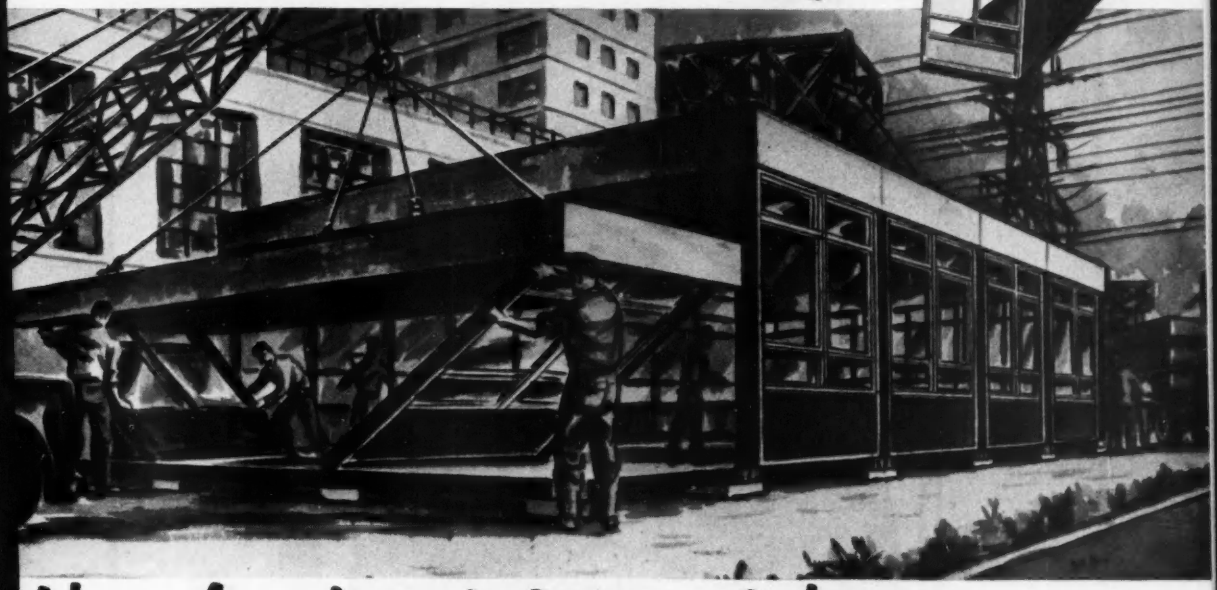

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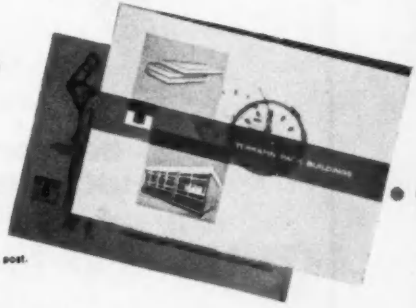

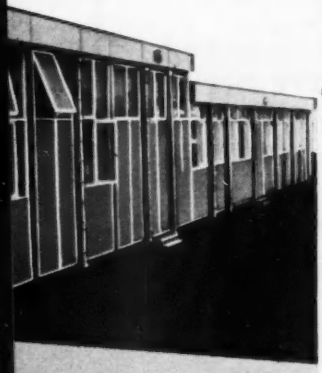

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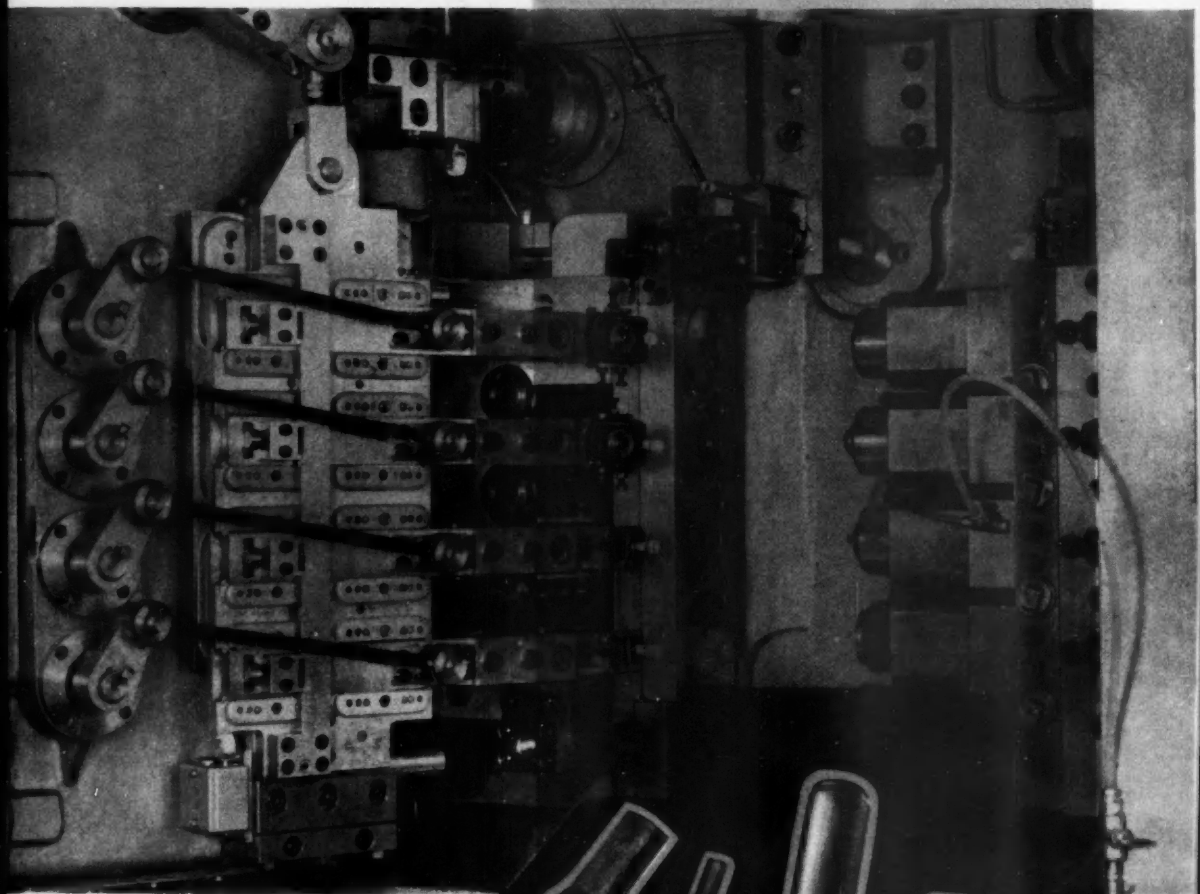

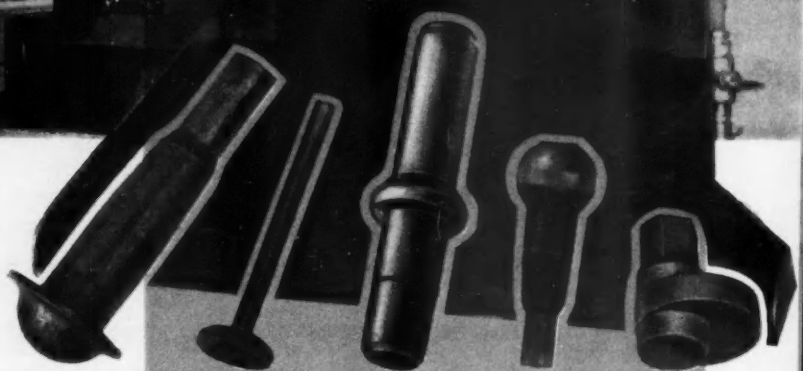

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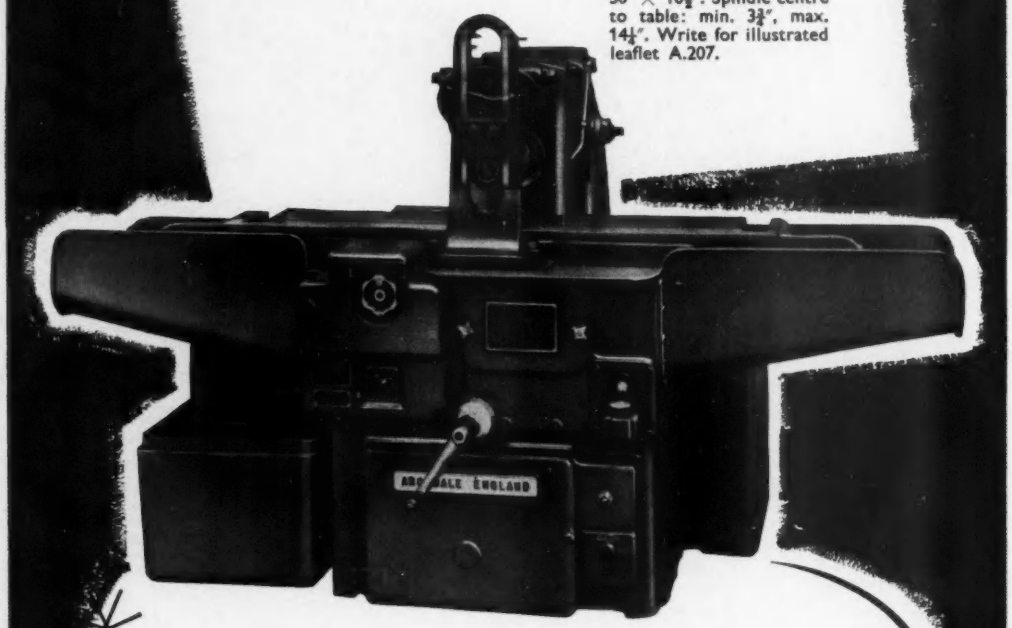

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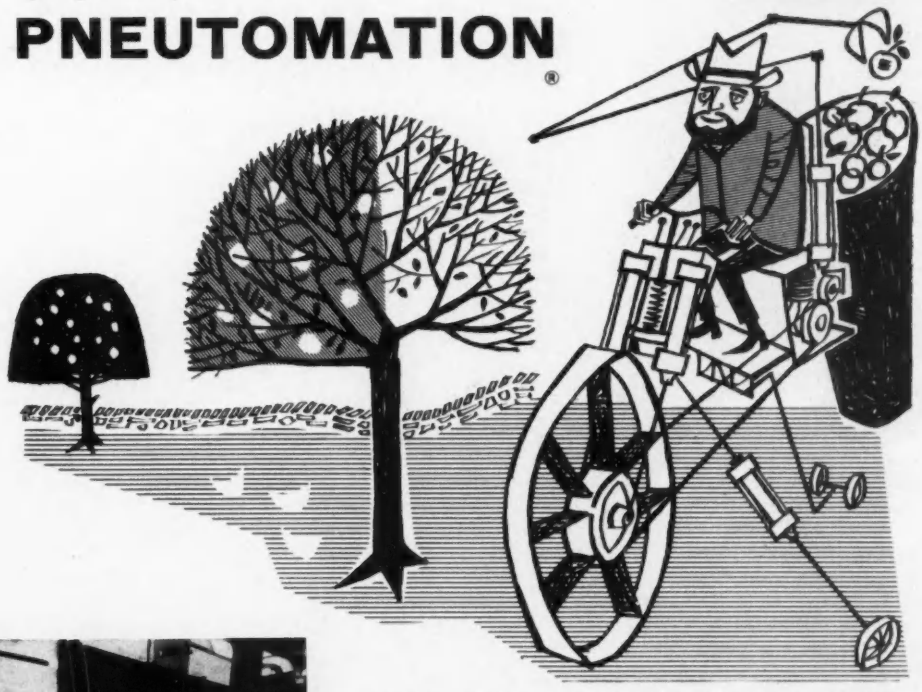

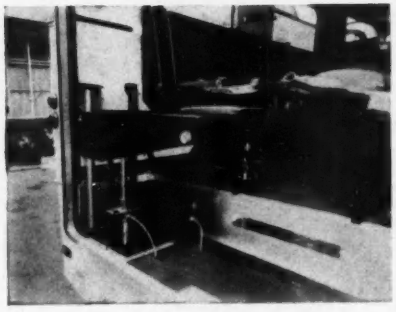

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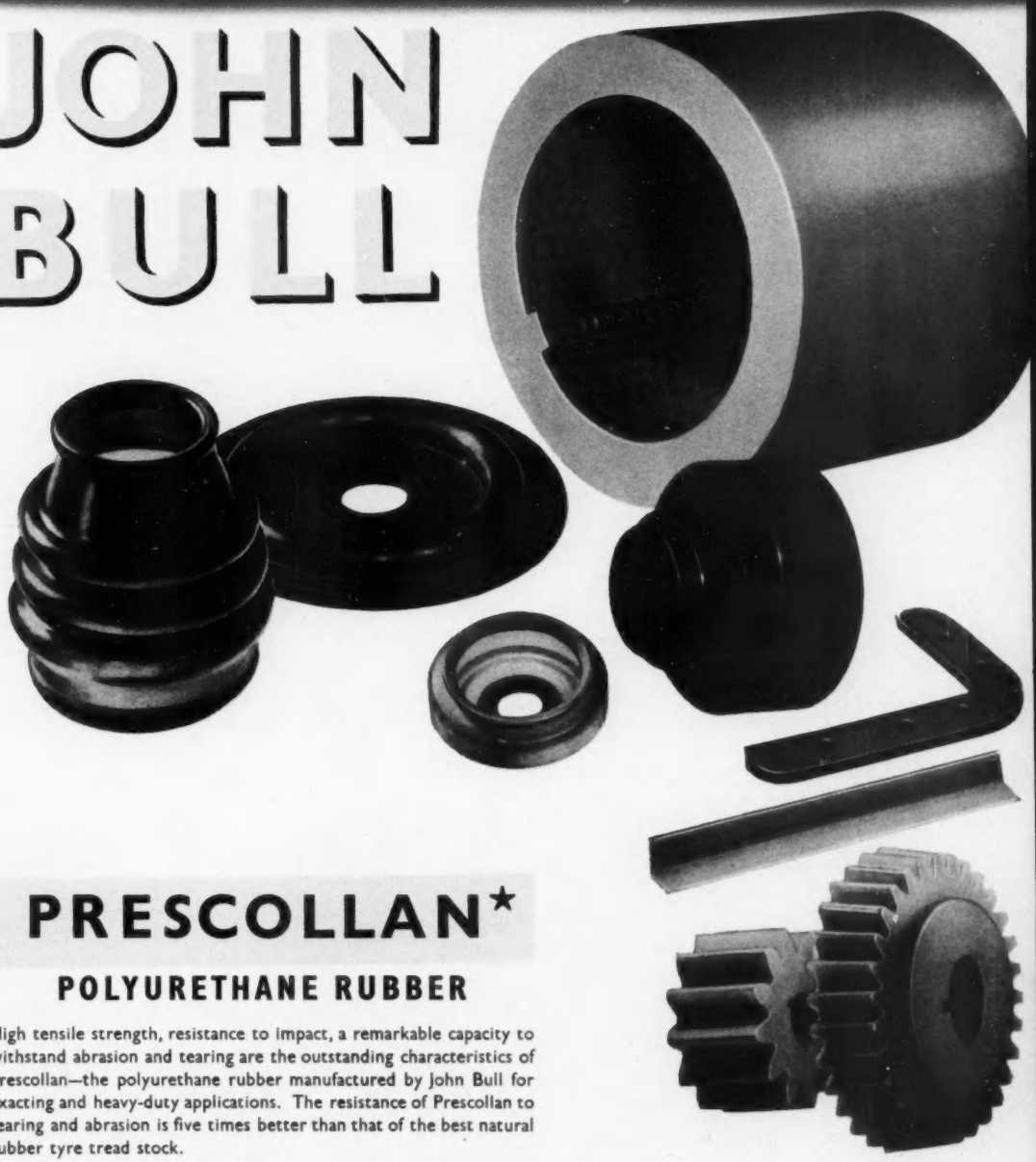

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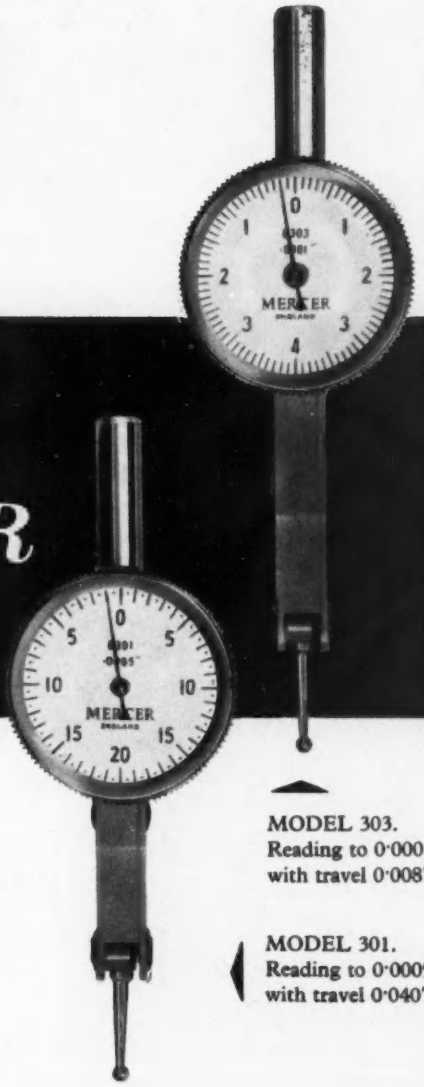

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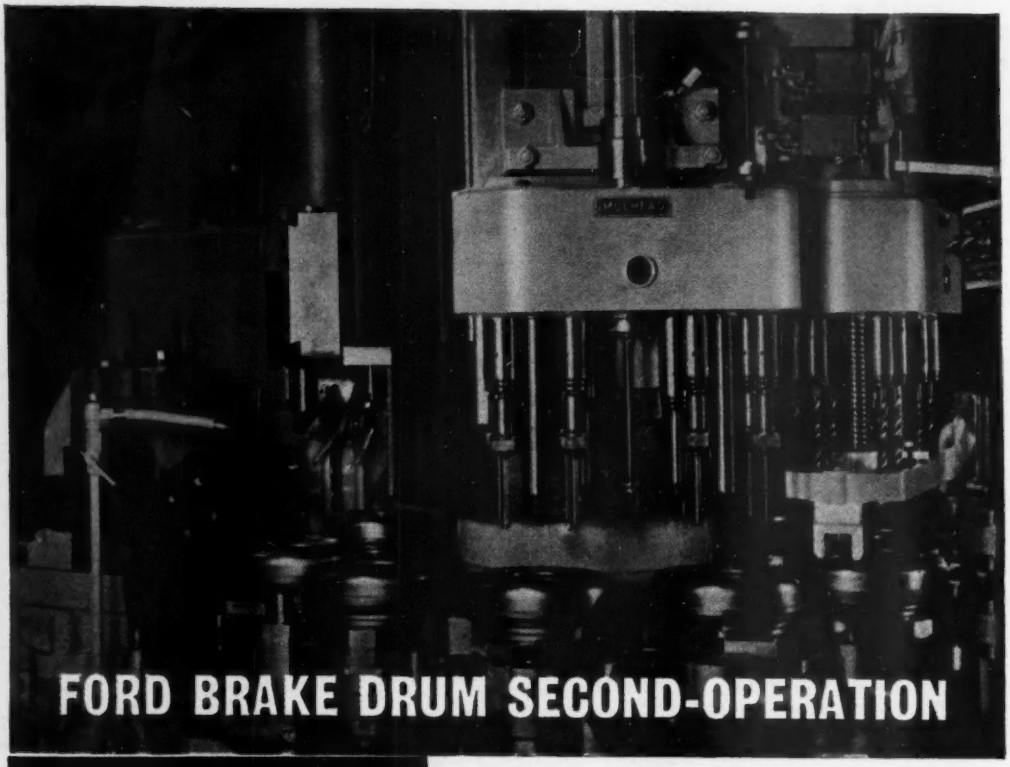

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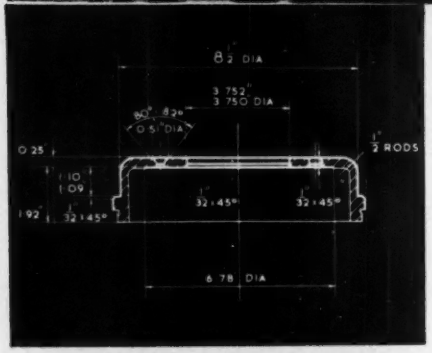

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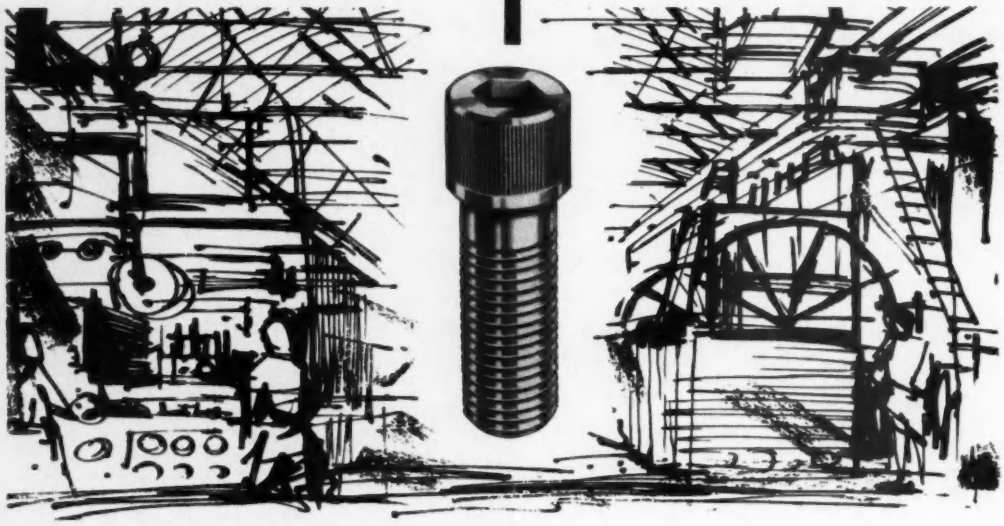

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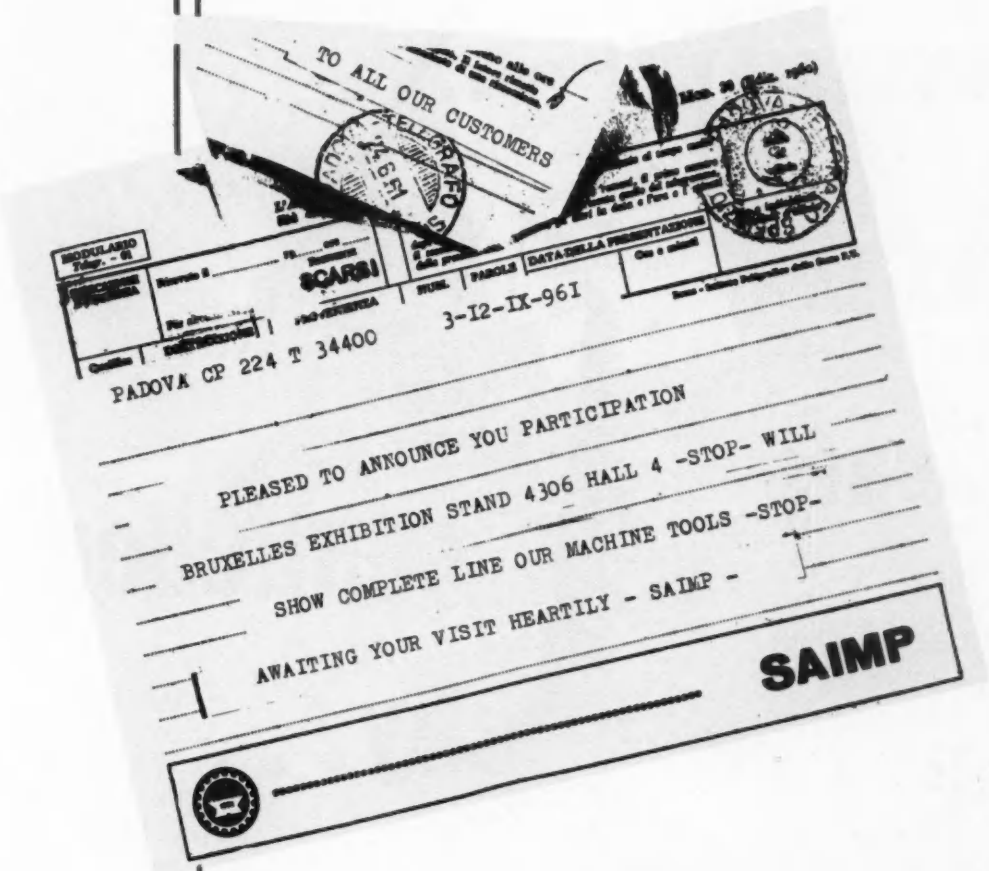
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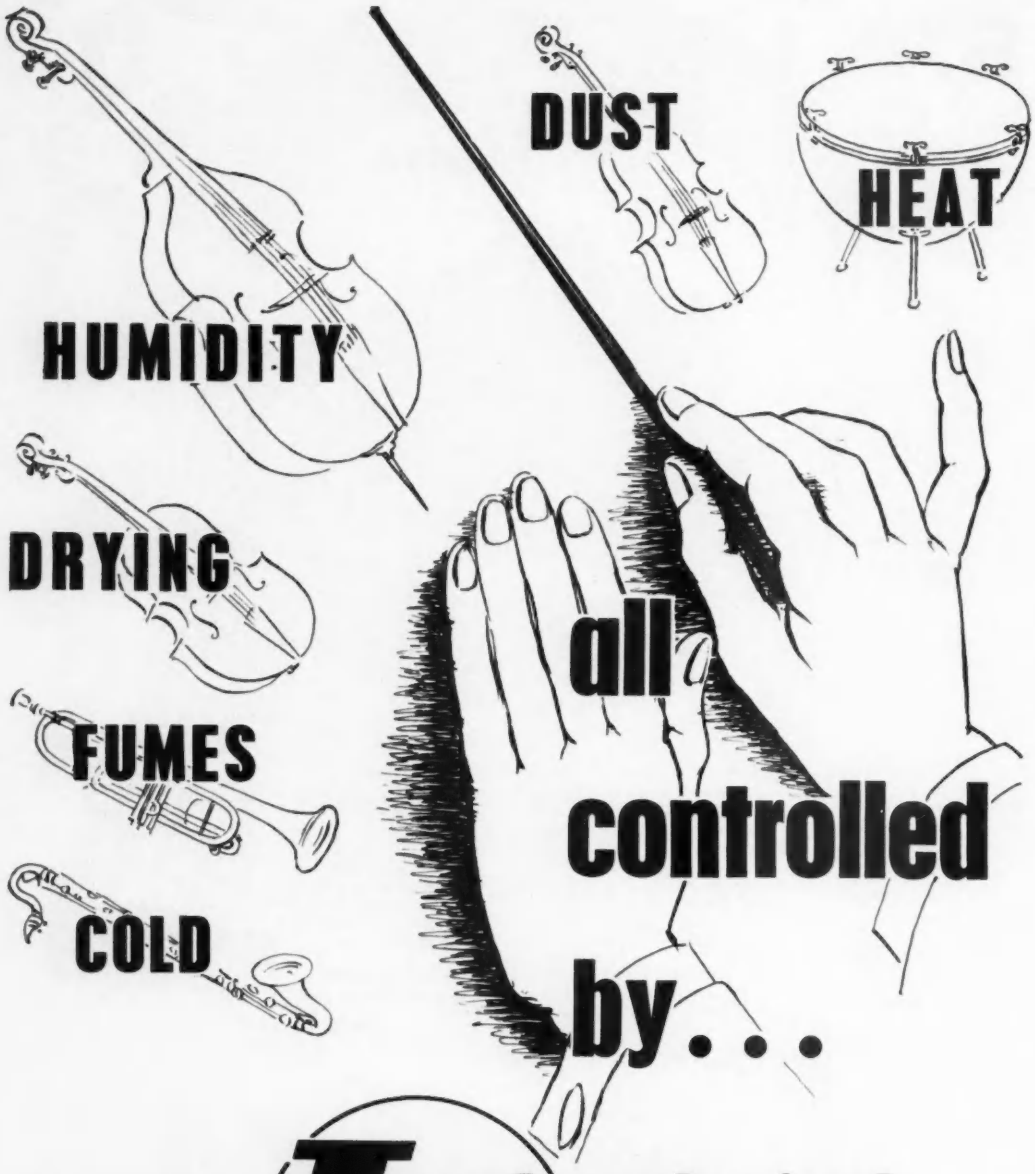

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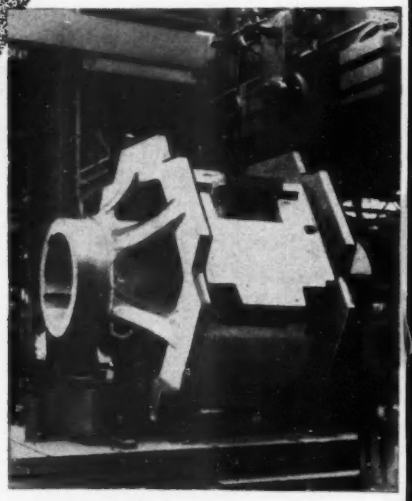

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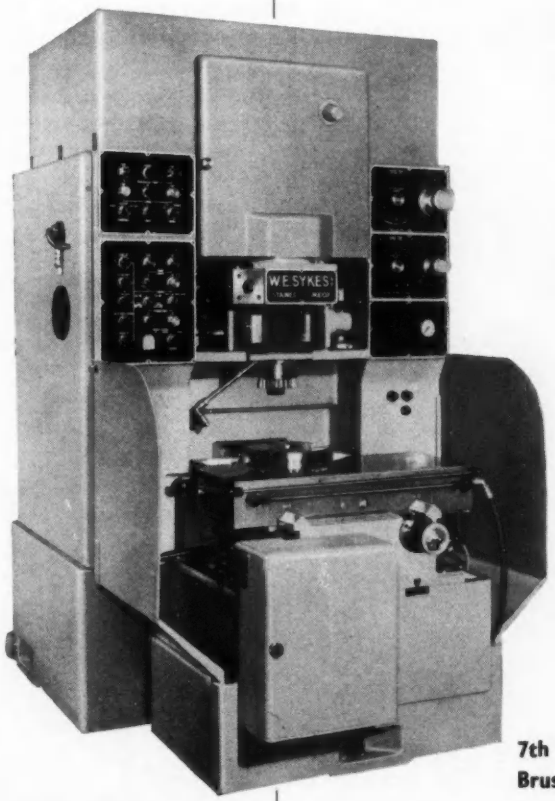

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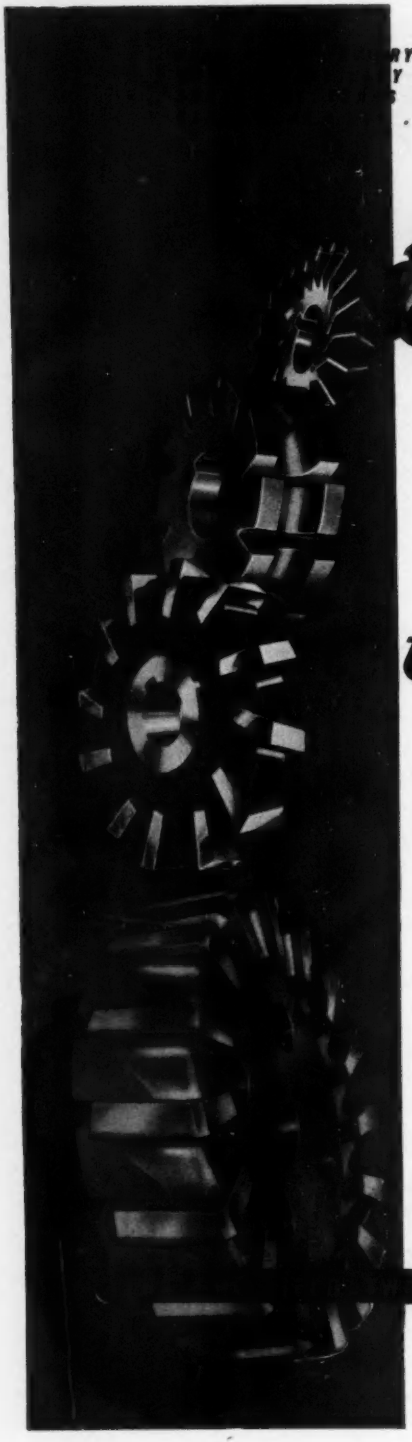

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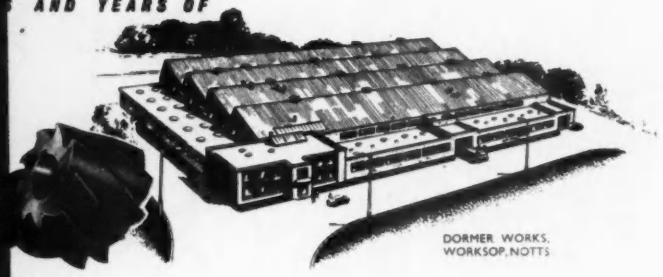

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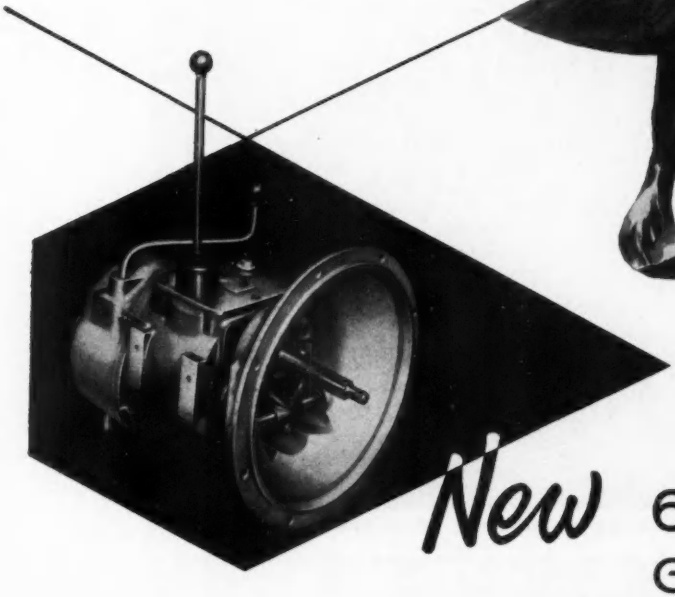

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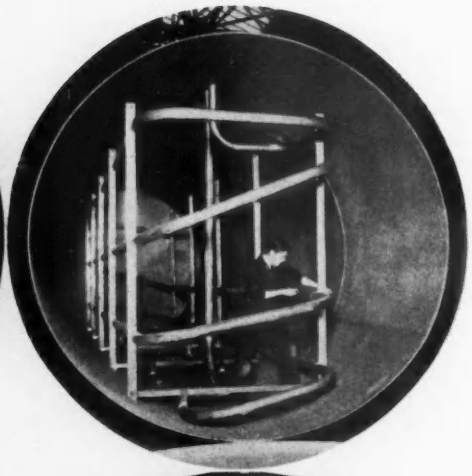

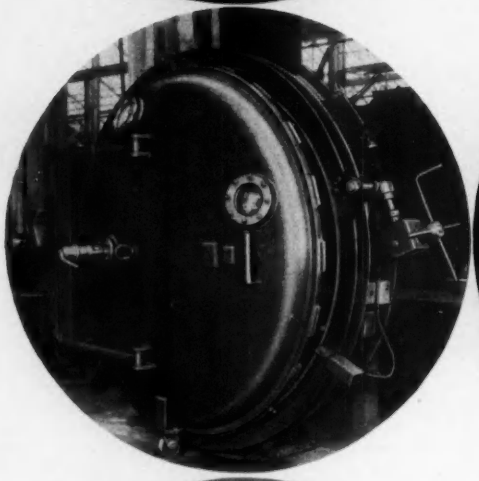

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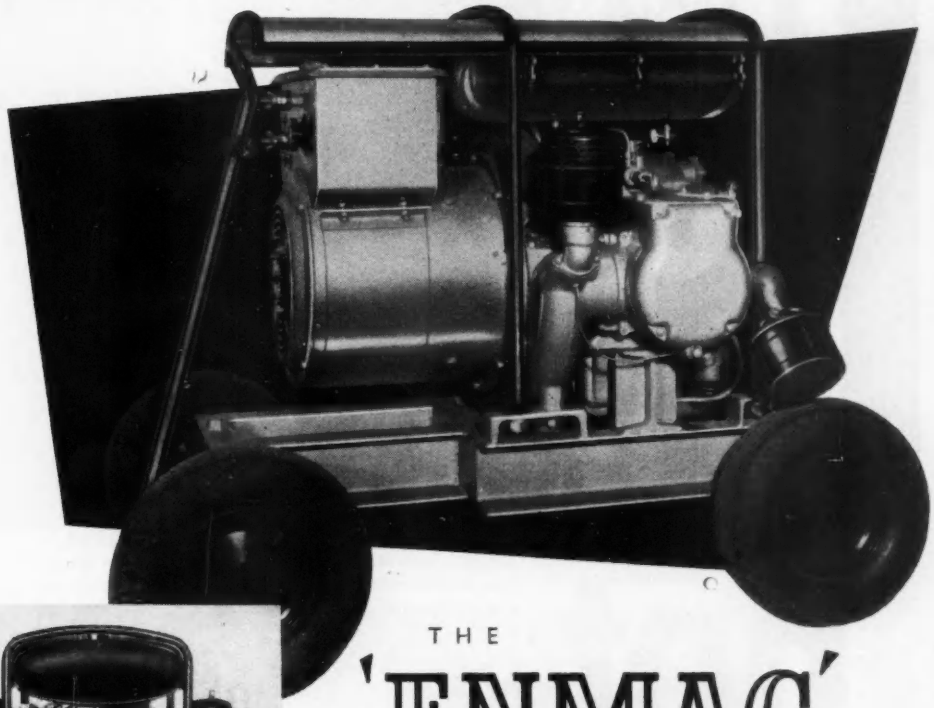

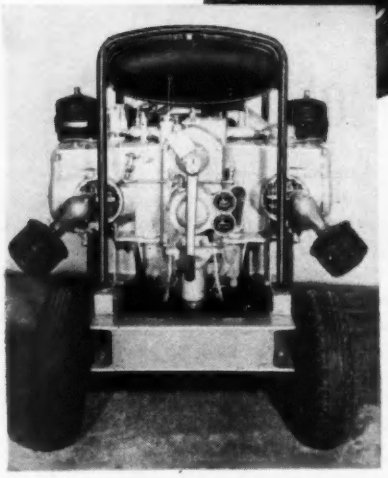

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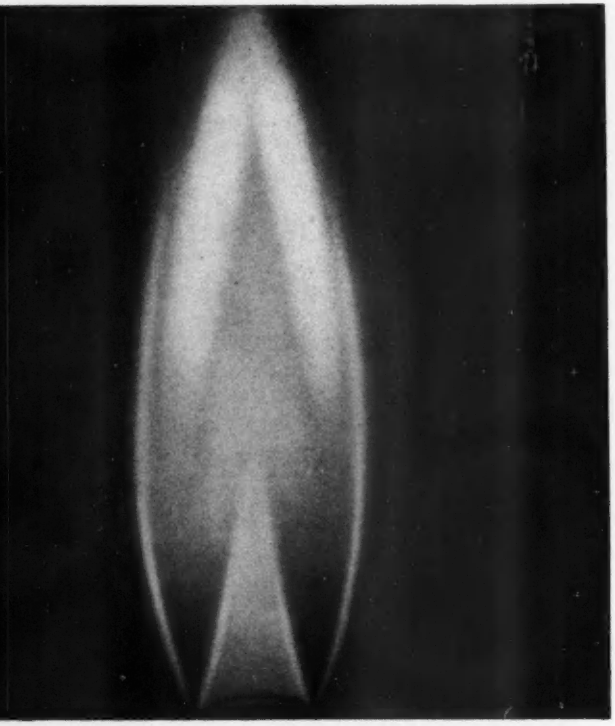

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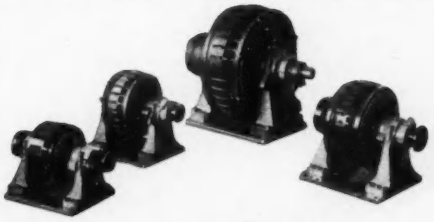

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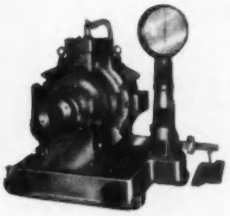

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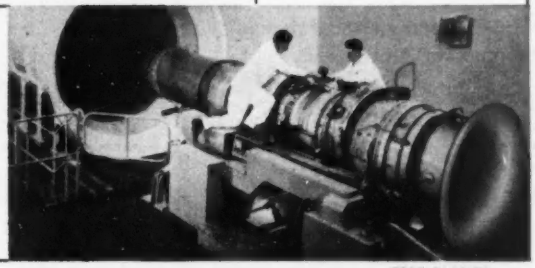

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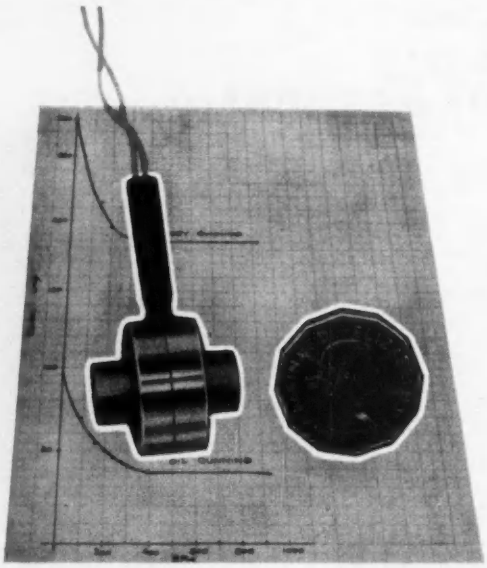
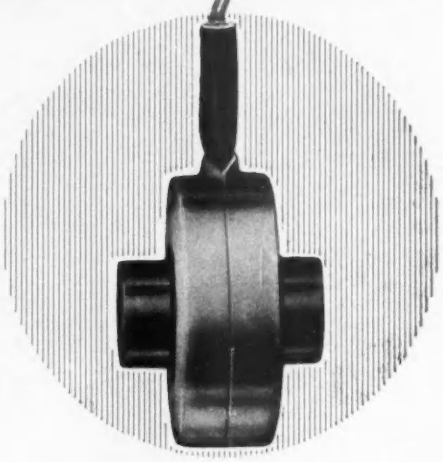


down to the minute



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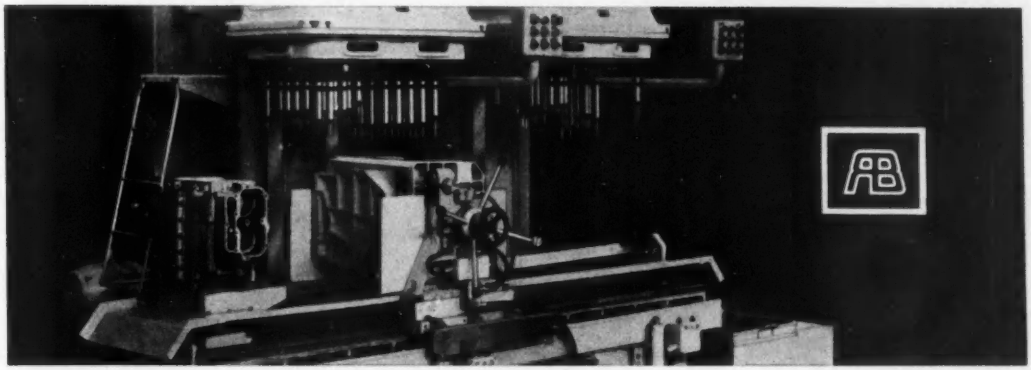
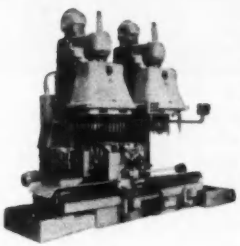


SHUTTLE TYPE MULTISPINDLE MACHINE VCM III SUITABLE FOR TAPPING



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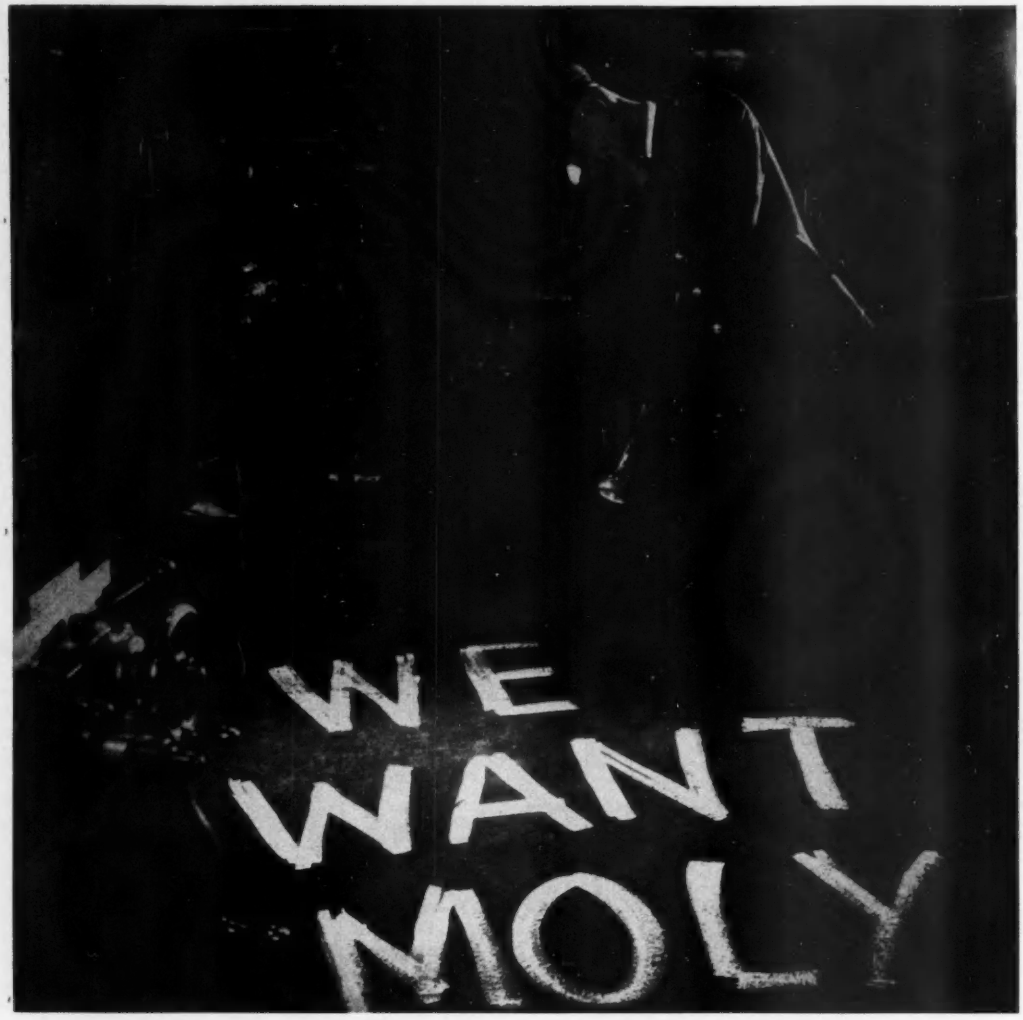

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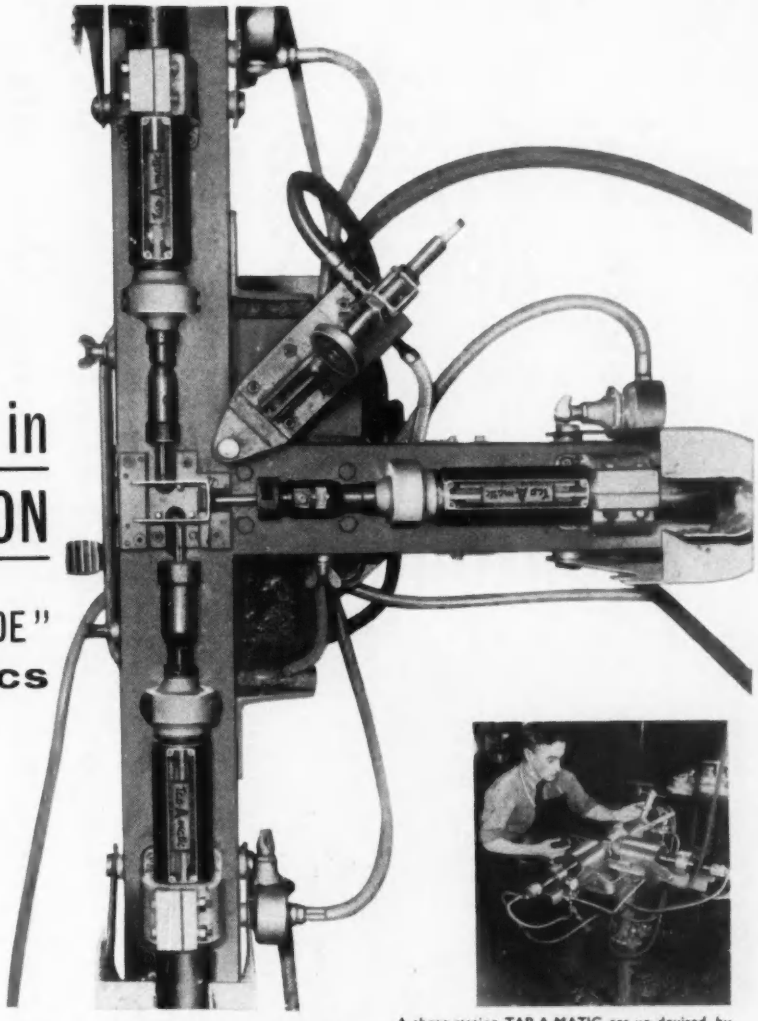

"ARO-BROOMWADE" TAP-A-MATICS enable multiple tapping to be performed where previously only single tapping was possible. This can effect significant increases in production rates.

Frigidaire, Division of General Motors Ltd., obtained a substantial increase in the production of stainless steel switchframes by installing the TAP-A-MATIC set-up illustrated above. A large number of variations and set-ups are possible. Why not discuss *your* production bottlenecks with a "BROOMWADE" works-trained representative? Why not write NOW?

Publication No. 443 *T.E. will give you preliminary data.*

A three-station TAP-A-MATIC set-up devised by Frigidaire, Division of General Motors Ltd., for tapping U-shaped stainless steel switchframe brackets. The following holes are tapped simultaneously:

$\frac{5}{16}$" × 24 T.P.I. right-hand thread.

$\frac{5}{16}$" × 40 T.P.I. left-hand thread.

14 × 40 T.P.I. right-hand thread.

The TAP-A-MATIC unit has given trouble-free service ever since it was installed two years ago.

Photograph by courtesy of Messrs. Frigidaire, Division of General Motors Ltd.

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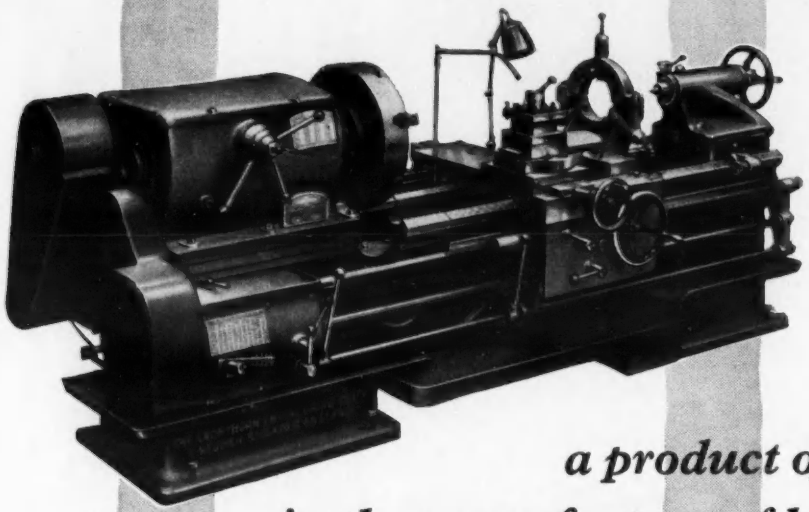

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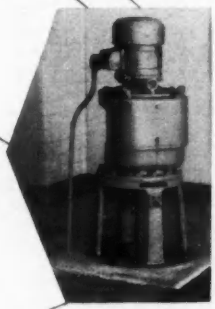

Motor and gearbox unit elevated above flood levels.

Hardy Spicer, already widely known in the Automotive and Railway industries, are supplying increasing quantities of drive shafts and universal joints for a variety of engineering applications. Typical of these are the shafts used to transmit driving power to the Jones & Attwood 'Comminutors' in the Stafford Borough Council's main sewage pumping station at Lammascote Road, Stafford.
(*T. H. Higson, Borough Engineer.*)

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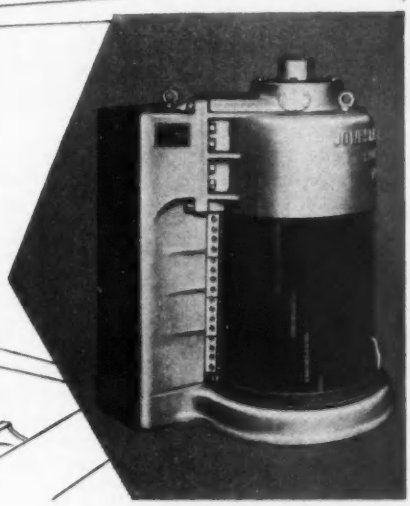

Hardy Spicer extension shafts, with universal joints, couple the electric motors on one floor with the Comminutors working in the liquid sewage a floor below.

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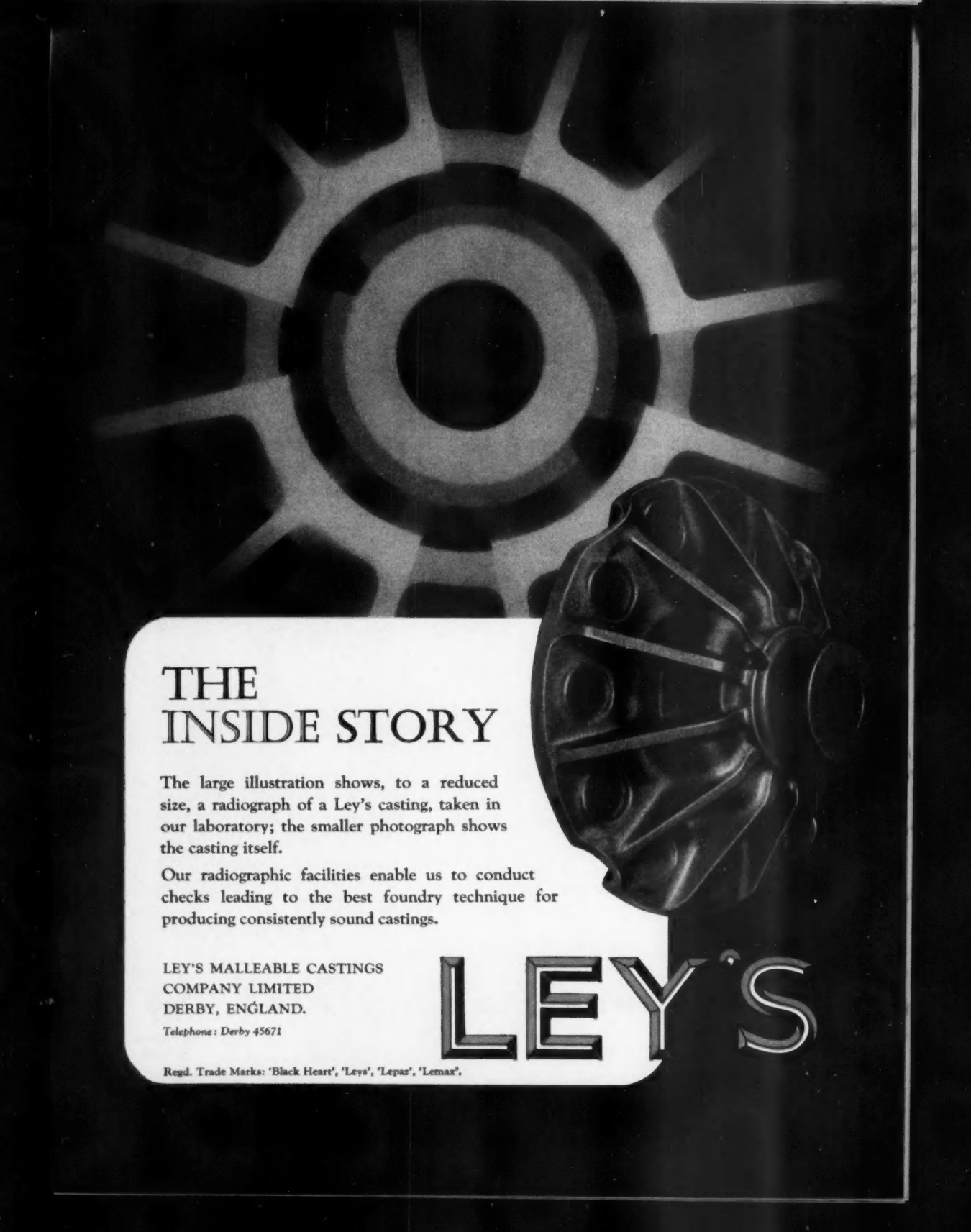

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *"FUNCTIONAL-BLOCK" RADIO RECEIVERS*

Using a functional-block concept to integrate, in a solid block of material, functions normally performed by complex electronic circuits, a new radio receiver containing no transistors, valves, or traditional electronic circuits has been constructed to test the feasibility of applying molecular electronics to complicated systems. The blocks are made by arranging the structure of a solid in such a way that phenomena occurring within or between domains of molecules perform the required electronic functions.

The main components of the receiver are six silicon wafers, each about $\frac{3}{4}$ in. in diameter. Each wafer is a functional electronic block which performs a complete function required for radio reception. Although the system is not directly comparable with conventional circuitry, it can be considered as consisting of six stages, i.e., two radio-frequency amplifiers, a radio-frequency tuner, a buffer, a detector, and an audio-frequency amplifier. The receiver, which caters for all stations in the standard broadcast band, is tuned simply by changing the voltage on one of the six functional blocks. By contrast, a conventional receiver with similar capabilities requires the use of about 50 individual components and about 150 soldered connections.

From *Westinghouse Engineer*, U.S.A., May 1961, p. 96.

● *METHOD OF INHIBITING CORROSION IN DIESEL ENGINES*

In many internal combustion engines, and especially in diesel engines, it is a common practice to provide the cylinders with a chromium-plated lining to reduce mechanical wear. However, the increasing use of sulphur-containing residual oils as fuels, particularly in marine diesel engines, has given rise to the problem of increased wear on these linings, apparently as a result of corrosion by sulphuric acid vapour. It is now reported that tests have shown that this corrosion is caused or accelerated by galvanic phenomena, the occurrence of corrosion being conditioned by the fact that metals of different positions in the electromotive series are present. As a result, when a sufficiently conductive electrolyte is also present, a galvanic cell, with a closed circuit through which a current can flow, is formed. Thus, a system comprising the chromium-plated cylinder wall, the acid oil film, and the cast-iron piston ring or the piston itself forms an electrical element which, when allowed to supply current, e.g., by short-circuiting, can cause partial dissolution or corrosion of one of the two poles involved, i.e., the chromium-plated lining or the cast iron.

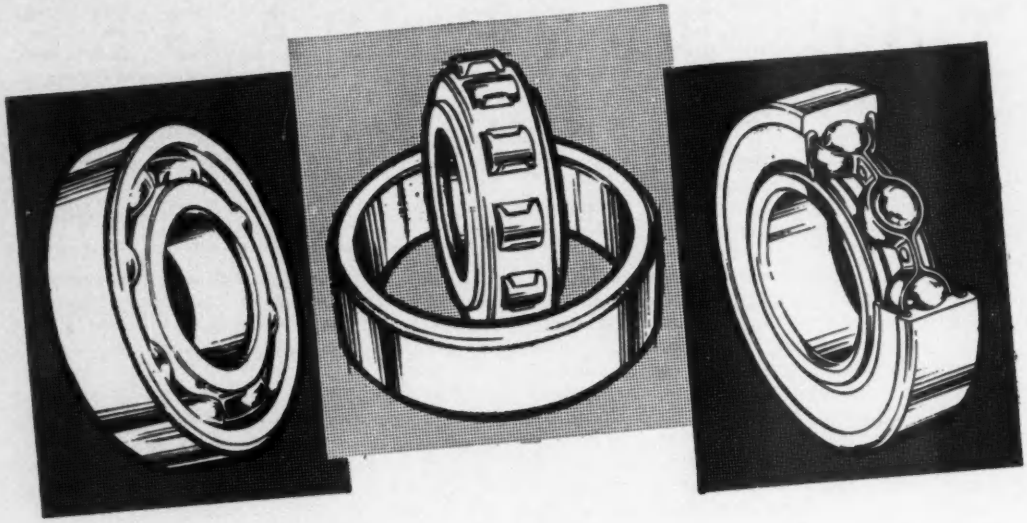
Stemming from this discovery, a recently patented method of inhibiting corrosion in diesel engines is based solely on providing adequate means of preventing short-circuiting. This is achieved simply by electrically insulating the pistons from the connecting-rods by means of suitable inserts, such as a layer of nylon or some other synthetic resin. In this way, it is impossible for an electric current to flow in a closed circuit from the cylinder lining through the piston, the connecting-rod, and other engine components back to the cylinder lining and, as a result, it is stated that corrosion of the lining or other metal parts is eliminated or very greatly retarded.

From *Brit. Pat. Spec.* 870,199.
H. van der Horst, Hilversum, Netherlands.

● *MINIATURIZED PNEUMATIC COMPUTING ELEMENTS*

A new pneumatic computing element basically comprises a tiny ball moving freely, but not loosely, in a narrow cylinder incorporating four tubular connections. When two of the connections are supplied with gas and the other two connections are vented to the air, the ball assumes either of two stable states, i.e., at the top of the cylinder or at the bottom. It is stated that this element has demonstrated all the necessary functions of arithmetic and logic required in a digital computer and that it can be miniaturized to such an extent that component densities of from 2000 to 4000 units per cubic inch are possible. In fact, it is believed that it is quite feasible to produce a general-purpose computer for missile guidance, business machines, and a process control, occupying a volume of no more than $5\frac{1}{2} \times 5\frac{1}{2} \times 1$ in. Also, because its construction would be based on the use of ceramic plates into which holes and slits are etched, such a computer should be able to operate under temperature conditions ranging from -100 to $+2000$°F without special provisions for heating and cooling.

With the new type of element, switching



FBC BALL & PARALLEL ROLLER BEARINGS

With augmented resources and an extended range of bearings, FBC are enjoying an upward trend in the scope and volume of their business. Evidence of the quality of their bearings in service is shown by the fact that FBC are major suppliers of bearings for Rolls-Royce jet engines.

Shown above are typical FBC bearings; left, the deep-groove type, centre, parallel-roller bearing, right, sealed pre-lubricated bearing, interchangeable with standard bearings: this bearing has proved most successful since it needs no access for lubrication.

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times of 10 microseconds are possible. In a computer application, the elements would primarily receive pulses as inputs and receive a pressure rise as an output, and, although the designers of the computing element have not as yet actually constructed a pneumatic computer, they have designed buffering, oscillator, and isolation circuits as interconnections. A special characteristic of this bi-stable element is its easy conversion from pneumatic to electrical signals, as the position of the metallic ball can be detected by means of a coil or capacitor plates embedded in the cylinder walls. Similarly, electrical to pneumatic conversion can easily be produced by forcing the ball to move magnetically or electrically. In this way, electrical test equipment can be built into the computer.

From *Control Engineering*, U.S.A., July 1961, pp. 22–23.

● *CLOSED-CYCLE GAS-COOLING SYSTEM USING AN EXPANSION TURBINE*

In cooling systems for gaseous media of the type employing an expansion turbine for expanding and cooling the gas and a compressor driven by the turbine, the compressor normally draws in air from the atmosphere and later blows it back again to atmosphere. In a new cooling system of this type, the compressor forms part of a closed gas cycle or compressor cycle which contains a cooler for the gas in this cycle and a throttling member in series, but which does not include the turbine or any heat exchanger for heating the gas in the closed cycle. In this way, the compressor cycle can be supercharged, so that greater masses of air are enabled to pass through a compressor of given size than is possible with conventional arrangements, and consequently the energy carried away by the compressor is greater. If the pressure in the compressor cycle is approximately the same as that of the gas stream through the turbine, it is sufficient to seal the interiors of the turbine and the compressor from each other by means of a simple packing, e.g., a labyrinth packing. If desired, the compressor cycle can contain the same gas as that passing through the turbine. In this case, any gas (e.g., a refrigerant) passing from the compressor cycle into the turbine cannot cause damage to the turbine cycle.

In a typical arrangement of the system, the turbine rotor and the compressor rotor are mounted on a common shaft carried by a bearing which is lubricated with gas originating from the compressor cycle, the gas subsequently being returned to the compressor cycle. The common rotor shaft can be encircled by an annular chamber to which is connected a pressure-equalizing passage for the supply and discharge of gas. In this way, the pressure in the annular chanber can be brought to the level of the pressure prevailing in the turbine, ensuring that no gas can flow from the compressor cycle into the turbine cycle. Thus, for example, the compressor cycle can easily be kept at a normal temperature of about 20°C, while the turbine cycle can have a temperature of about −90°C. The pressure-equalizing passage can be provided with an automatically controlled pressure-regulating device. Similarly, the throttling member in the compressor cycle can be controlled automatically, e.g., by a thermostat in a cooling chamber of the refrigerating plant.

From *Brit. Pat. Spec.* 870,091.
Sulzer Frères S.A., Winterthur, Switzerland.

● *IMPROVED ELECTROLYTIC-STRIPPING METHOD FOR REFRACTORY COATINGS*

Methods of removing refractory coatings mechanically, e.g., by grinding, are not always satisfactory, as they can be time-consuming and expensive, and sometimes remove excessive amounts of the base metal. Also, existing electrolytic-stripping methods using solutions such as aqueous sodium hydroxide or sodium carbonate are not suitable for stripping certain mixed refractory coatings in that either they fail completely to remove such coatings or their rate of removal is economically low.

To overcome these drawbacks, a new electrolytic-stripping method has been developed and is claimed to be able to remove rapidly and economically all the more difficult refractory coatings from metal base materials of any shape. In essence, the method involves the use of an electrolytic bath made up of an aqueous solution containing between 0·02 and 2% by weight of a water-soluble salt of a hydroxy organic acid and between 2·5 and 5·5% by weight of an alkali-metal carbonate. This bath is maintained at a temperature between 120 and 200°F, the material to be stripped being immersed in it and forming the anode of an electrical circuit with a current density of from 3 to 6 A/sq in. The water-soluble salt of the hydroxy organic acid can be either monocarboxylic or polycarboxylic, the sodium, potassium, and ammonium salts of tartaric and citric acid being especially suitable. The use of sodium tartrate is particularly recommended, as it provides the desired concentration with the least amount of raw material, owing to its low molecular weight. With regard to the alkali-metal carbonate, sodium carbonate is preferred as the means of providing the stripping bath with the desired current-carrying capacity, but other carbonates, such as potassium carbonate, are also suitable.

The bath is particularly suitable for stripping tungsten carbide/chromium carbide/nickel

Photo by courtesy of Fibres Division, Imperial Chemical Industries Ltd. Manufacturers of 'Terylene' polyester fibre.

C IS FOR CONVEYOR BELTS at a new I.C.I. plant in Cheshire, where eight Goodyear belts of rubber and 'Terylene' carry coke, burnt lime and coke/lime mixture. 'Terylene' was chosen for its flexibility and strength, which allows exceptionally deep troughing so that deck plates, skirt boards, etc., are eliminated and idlers can be spaced 50% wider apart. 'Terylene' also withstands the heat of the coke (carried at up to 120°C), is rotproof and resists moisture penetration. For the *right* conveyor belt, installed in the *right* way and maintained in the *right* manner, contact Goodyear Industrial Products Division at Wolverhampton.

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coatings and also for chromium carbide/nickel/chromium coatings. It can also be used for removing refractory coatings which can be stripped by conventional methods. For example, a tungsten carbide coating can be removed more rapidly by the new method than by the conventional sodium carbonate electrolytic bath. Also, the base metal on parts stripped by the new method is clean and bright and does not have the black deposits present on the base metal after stripping with previous electrolytic methods.

From *Brit. Pat. Spec.* 870,000.
Union Carbide Corporation, New York, U.S.A.

● ***COBALT-BASE ADDITIVES FOR REDUCING SOOT FROM OIL-BURNING EQUIPMENT***

It is known that the use of cobalt oxide for the complete catalytic combustion of the exhaust gases from petrol engines has shown promising results. It is pointed out in a recent article, however, that cobalt-base compounds can also lead to an improvement in the efficiency of domestic oil-burning equipment, as has been shown by a number of tests made to determine to what extent cobalt can contribute to the elimination of residual combustion products, such as soot, emitted from such equipment. In this connection, it is emphasized that the operating conditions in petrol engines are very different from those prevailing in domestic oil-burning equipment. Admittedly, it is relatively easy in such equipment to ensure combustion without too great an excess of air (and hence without excessive losses by exhaust products) and with very little solid residue, provided that the equipment chosen is adequate for the task and is correctly installed. Unfortunately, these prerequisites are not fulfilled in many cases, e.g., in equipment initially designed for coal and difficult to adapt for liquid fuel, in equipment fitted with an oil burner of the wrong design or size, or in equipment working far beyond or below its nominal capacity.

To determine the effects of cobalt-base additives on domestic oil-burning equipment under the operating conditions likely to be encountered in practice, the tests described in this article included the effects of excess air and of additive type and concentration on combustion residues, and also the effects of cobalt-base additions on the acid dew-point and on heat-exchanger efficiency. The results of these tests show that the addition of organic compounds of cobalt to fuel oils decreases the weight of combustion residues, independent of the operating conditions of the boiler. As a result, for a given weight of residue, cobalt additives permit the amount of excess air to be reduced, consequently reducing waste heat. On the other hand, it has been found that the use of these additives hardly changes the rate of fouling of exchanger surfaces in ordinary domestic boilers, and the increase in efficiency in this direction is insignificant. In addition, it has also been verified that these additives do not catalyse the oxidation of sulphur dioxide to sulphur trioxide, so that their use presents no risk of increasing corrosion in domestic heating equipment.

From *Cobalt*, Belgium,
June 1961, pp. 21-27.

● ***NEW HIGH-TEMPERATURE OXIDATION-RESISTANT BORON SILICIDES***

Following the successful development last year in the U S.A. of tetraboron silicide (B_4Si), a second boron silicide, hexaboron silicide (B_6Si), has now been produced by the same company. These ceramic-like materials, which are available as black, free-flowing microcrystalline powders, have been developed for use at high temperatures and have excellent thermal-shock resistance and outstanding oxidation resistance at temperatures up to 2500°F. Their high boron contents (60% for B_4Si, and 70% for B_6Si) should make them suitable for use in nuclear reactors as neutron control sources, as shielding structures, and as burnable poisons.

Both materials can be fabricated by conventional powder-metallurgy techniques and can readily be cold-pressed without binders, hot-pressed, slip-cast, and extruded. One of their most interesting characteristics is that that they can be sintered in air. If the material is cold-pressed at between 10,000 and 20,000 psi and sintered in air at about 2000°F, the formation of oxide bonds provides a body strong enough to be machined with ordinary machine tools, though the use of carbide tools is recommended. The machined part is then refired in air to 2500°F with virtually no shrinkage, forming an extremely hard and dimensionally stable body. During sintering, these silicides absorb oxygen, producing a coating of an amorphous phase, probably a silicon-boron-oxygen glass, which prevents further oxidation. Consequently, they can be used under conditions which would severely degrade boron carbide as well as other materials.

Tetraboron silicide is somewhat less stable at high temperature than hexaboron silicide, so that most experimental work has been carried out with the latter material. Bodies of oxide-bonded hexaboron silicide have been prepared with a density of about 106 lb/cu ft. Strength depends on sintering time; thus, after sintering in stagnant air for 24 hr at 2500°F, the bending strength is about 12,000 psi at room temperature, or about 10,000 psi after sintering at 2000°F. The thermal shock resistance of hexaboron

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silicide is exceptionally good, no cracking being observed after 50 cycles between 2000°F and room temperature in air. Furthermore, no cracking occurs when this material is heated to 2000°F and then quenched in water.

From *Materials in Design Engineering*, U.S.A., June 1961, pp. 9-10.

● *IMPROVED METHOD OF MAKING CAST HIGH-SPEED-STEEL TOOLS*

It is generally admitted that the use of cast high-speed-steel tools confers certain definite advantages over hot-worked steel tools of the same type, particularly in connection with the costs of processing and material. However, although attempts have been made in the past to produce cast high-speed-steel tools, the results obtained have been contradictory. Thus, for instance, it has been found that, in rough cutting, milling cutters made of cast steel have the same life as forged milling cutters, whereas turning tools made of cast-high-speed steel appear to have a substantially shorter service life than that of worked material of the same type.

To overcome these discrepancies, a recently patented method of making cast high-speed-steel tools has been developed, and it is claimed that its use enables all the advantages of a mould-casting process to be exploited and at the same time ensures that the life of the tools produced is at least the same as, and in many cases superior to, that of tools made from hot-worked steels of the same type. Essentially, the process involves subjecting the cast tools to annealing at between 1050 and 1200°C for from 1 to 8 hr, prior to conventional hardening treatment.

It is stated that this annealing treatment can be applied to all known high-speed-steel alloys and leads to surprising increases in tool life, especially in the case of cobalt-alloyed high-speed steels. For example, tests have been carried out with this process to make tools from a steel alloy containing 1·65% C, 12·5% W, 4% Cr, 4% V, and 5% Co. These cast tools were annealed for 1 hr at 1100°C and then cooled in air, after which they were hardened by first preheating to 850°C, then raising them to a temperature of from 1230 to 1260°C in a salt bath, quenching in oil, and tempering twice, in each case for 1 hr at 570°C. These tools were then tested in a milling operation and were found to be satisfactory over an average cutting distance of 2400 metres. By comparison, tools made of the same alloy and subjected to the same treatment, with the sole difference that the annealing step was omitted, were found to have an average cutting distance of only 1000 metres in a similar milling operation.

From *Brit. Pat. Spec.*, 873,529.
Gebr. Böhler & Co. A.G., Vienna, Austria.

● *PROCESS FOR PRODUCING BOILER FEED-WATER*

It is known that, in contradistinction to a boiler feedwater containing only sodium ions, a water containing both sodium and potassium ions tends to suppress the formation of mineral deposits in heat exchangers, and also eliminates or considerably diminishes the formation of siliceous deposits in the boiler. For this reason, various methods have been proposed for supplying a certain amount of potassium ions to boiler feedwater, either by adding potassium phosphate, potassium sulphite, or potassium chloride to the water, by introducing potassium hydroxide or potassium carbonate during the softening of hard feedwater, in place of the more usual sodium hydroxide or sodium carbonate, or by using potassium chloride, instead of sodium chloride, for regenerating base-exchange filters. Unfortunately, the substantially higher cost of potassium compounds has prevented their wide use in precipitation and ion-exchange methods of water softening.

It is now reported, however, that, based on the observation that only a limited concentration of potassium ions in boiler feedwater is necessary to secure all the desired advantages, a new process has been developed which yields feedwater having a limited concentration of potassium ions, while a larger equivalent amount of sodium ions, which are no longer harmful, can remain in the water. This concentration is dependent on the concentration of silicic acid in the hard water and is from 4 to 5 times the amount of the concentration of silicic acid expressed as equivalents. In this way, it is possible to dispense with costly additional purification operations to remove silicic acid from the feedwater.

In carrying out the process, hard water is filtered through a base exchanger charged with sodium and potassium ions after first being softened by at least one sodium-base exchanger. By adjusting the ratio of sodium to potassium ions in the solution used to regenerate this final base exchanger, it is possible, depending on its total salt content, to produce in the feedwater a concentration of potassium ions corresponding to any particular requirement.

From *Brit. Pat. Spec.* 873,309.
VEB Farbenfabrik Wolfen, Wolfen, Bitterfeld, E. Germany.

Readers desiring further information on any developments reported in THE BLUE PAGES are invited to write to the Editor. Copies of the full specifications of any British patents mentioned, which are published by courtesy of H.M. Stationery Office, should be obtained from the Patent Office, 25 Southampton Buildings, Chancery Lane, London, W.C.2. Price 3s. 6d. each.

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Recent Developments in the Numerical Control of Machine Tools

BY

R. C. Brewer

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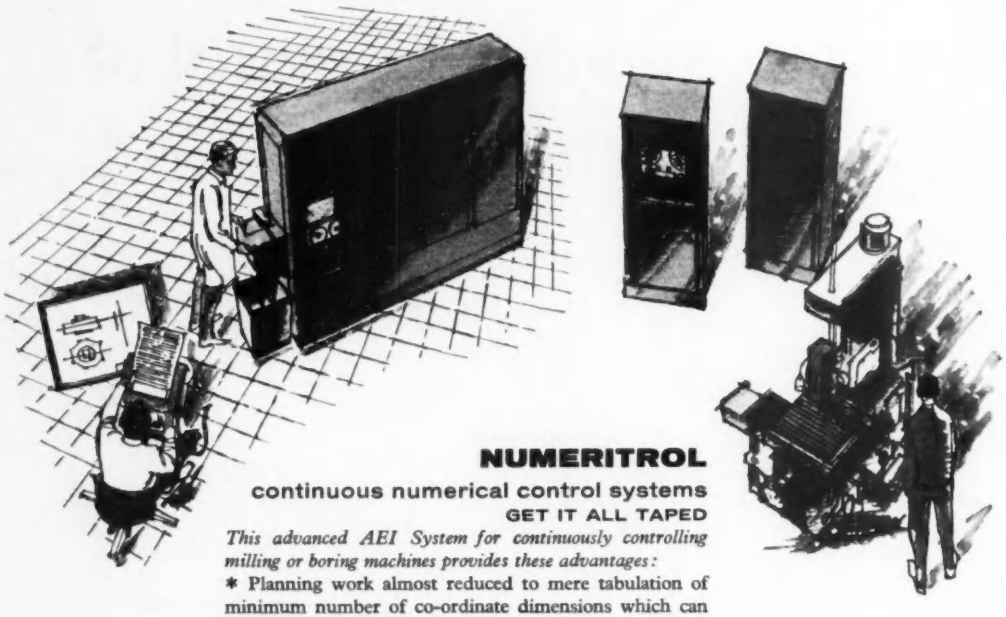

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Recent Developments in the Numerical Control of Machine Tools

By R. C. BREWER*

THE first edition of the author's survey, "The Numerical Control of Machine Tools"[1], was published in September 1958, when it might have seemed, from the number of systems available, that numerical control was well-established, in the U.S.A. at least. On the basis of sales, however, this was not the case and, in retrospect, it appears that interest in the subject was very superficial.

To some extent, this is understandable, since numerical control is a fusion of techniques from the fields of computer technology, control engineering, electronics in general, and telecommunications in particular—all fields alien to the average machine-tool user. Indeed, one of the main purposes of the original survey mentioned above was to explain numerical control to the non-specialist. The information available at that time from engineering journals was vague and scattered, while probably no other field could equal control engineering for density of technical jargon per printed page.

A second reason for the slow response to numerical control was its high cost. In the U.K., prices ranged from about £1,000 to £16,000, and the ratio of control-system cost to machine-tool cost could be as high as 3 : 1. Machine-tool users need convincing of the certainty of regaining costs such as these before purchasing, and it is probably here that the advocates of numerical control failed most lamentably, although not for want of trying. Indeed, it is still true that one of the greatest difficulties in promoting numerical control is to give concrete evidence of savings, and the protagonist is constantly hampered by the fact that many of the savings of numerical control are intangible.

What of the contemporary position? Numerical control has undoubtedly made the greatest progress in the U.S.A. At last year's Chicago Exposition, some 70 numerically controlled machine tools were exhibited. Furthermore, this is the only country in which any kind of survey appears to have been conducted. The "American Machinist" survey[2] elicited 1107 replies from 5000 questionnaires. Of these 1107 companies, only 94 answered the nine questions requested on numerical control and, since companies were asked to answer these questions only if they had numerically controlled machines or had decided to purchase one or more, it appears that even American industry is poorly equipped with numerical control. These 94 companies had 116 controlled machines installed, 48 on order, and 127 planned for the next eighteen months (say, August 1960 to February 1962). Of these 291 machines, 218 were accounted for by only three industries, i.e., the aircraft industry, the machine-tool builders themselves, and manufacturers of special-purpose machinery. Classified another way, 78% were positioning systems and 22% were continuous contour control systems, the latter largely accounted for by the U.S. Air Force Programme.

About one-fifth of the companies said that they were interested in numerical control in order to reduce direct labour. Other reasons given were reduction in tooling, increased output, improved product quality, and better flexibility. 95% of the companies anticipated that the equipment would pay for itself in from 2 to 5 years and, perhaps rather surprisingly, 75% anticipated using numerically controlled machines on a two-shift basis.

Only 28% of companies replying used a special data-processing group, 68% depending on their Methods Engineering Department; also, 55% used their regular maintenance staff for numerical control systems. Their replies to these two questions do much to dispel fears that numerical control can be introduced only if new specialist staff is recruited.

Interpretation of small samples is difficult, but it would appear that, in the U.S.A., there is a fairly wide choice of good control systems and, with the machine-tool builders looking for a sales boost after the recession, numerical control is gathering momentum slowly, but steadily.

As might be expected, drilling and boring machines account for the majority of positional control systems, while milling machines take most of the continuous contour control systems. The second edition of the author's survey[1] appeared concurrently with the introduction of the "Milwaukee-matic"—one of the first of the universal tool-changing machines—and contained some reference to it. Since then, interest in tool-changing machines has increased considerably.

A significant American trend is the increasing amount of control applied to centre and turret lathes. At the 1955 Chicago Exposition, only one controlled lathe was exhibited, but now there are several lathes available, the majority being specially designed for numerical control. The Boeing company has a numerically controlled Jones and Lamson turret lathe and, in conjunction with IBM, has developed a special computer programme to check that tapes do not carry data which might lead to tool collisions.

The situation in the U.K. cannot be said to have progressed as much as in the U.S.A. but the attendance at courses on numerical control, held in various parts of the country, testifies to an increase in interest. It is probably fair to say that British control systems are steadily consolidating their position in American and European markets and are leading to what may well mark the beginning of a snowballing trend.

Interest has at last been aroused in Continental Europe. Thus, at the Italian Machine Tool Show in November 1960, Italian numerical control was seen for the first time. Olivetti exhibited a cam milling machine equipped with an analogue contouring system, while San Rocco and Caser both showed positional-control machines. Several German systems are now available, and Belgium, France, and Sweden certainly have at least one control system each.

It is the object of the present survey to outline the developments which have taken place since the publication in 1959 of the second edition of the author's survey[1].

(1) R. C. BREWER: "The Numerical Control of Machine Tools", The Engineers' Digest, 1st edition, September 1958 and January 1959; 2nd edition, September 1959.
(2) ANON: *American Machinist/Metalworking Manufacturing*, Vol. 104, No. 17, p. 167.

* Imperial College of Science and Technology, London.

With this in mind, it is proposed to discuss, first of all, the components of the system—hardware, in the control engineer's jargon—and this part will be divided into sections dealing with permanent storage media. transducers, and machine-tool elements. The second and third parts will be devoted to a discussion of new and modified systems, these being divided into positional control and continuous contour control. The fourth part will deal with the problem areas of numerical control, i.e., the stages between the design drawing and the control system, economic questions, and the design of machine tools for numerical control.

It is not proposed to give any general introduction to numerical control, as this was done in the previous survey, or to discuss the way in which numerical control fits into the manufacturing system, since this has been done previously for production processes in general[3] and for machine tools in particular.[4].

CONTROL-SYSTEM COMPONENTS

Permanent Storage Media

During recent years, there have been many developments in permanent storage media, and it seems apposite to discuss briefly the contemporary position.

In the previous survey, it was evident that punched tape was becoming the standard input medium for both positional and continuous contour control systems. Confirmation of this trend can be seen by reference to Tables I and II. One obvious advantage is cheapness. At roughly a halfpenny per 100 ft, i.e, 1500 characters, it would be difficult to reduce the material cost, while the capital cost of the associated equipment is not expensive, unless very high speeds are required. Punched tape has the advantage over magnetic tape that the pattern is visible and, with practice, can be read. Over punched cards, it has the advantage that serial information cannot get out of sequence, although, by this token, it shows its one disadvantage, i.e., that it is more difficult to make minor modifications to information on punched tape than to that on punched cards.

A further technological advantage, which at the moment is unfortunately more apparent than real, is the potentiality to send data on 5-channel tape over the normal Telex system to any country in the world subscribing to the International Telegraph Convention. The moot point at present is the accuracy with which the data can be transmitted over Telex lines, and the current trend is to evolve methods of checking for errors. For example, at intervals, a check sum of all the figures transmitted since the last check sum is interpolated in the numerical data; the figures are also added at the receiving end by independent means and are used to verify the check sum. Should there be any disagreement between these two summations, the whole of the data since the last check sum is re-transmitted.

When used for standard telegraph purposes, punched tape has 5 channels, so that the number of unequivocal combinations is $2^5 = 32$, or 31 if the no-hole set is excluded. This suffices for the Roman and Cyrillic alphabets and, by the use of an artifice similar to the shift key on a typewriter, numerals and punctuation marks can be coded (this use of the shift key means that there is ambiguity about the meaning of any particular pattern of holes, and distinguishing symbols such as l.c. (lower case) and u.c. (upper case) must be used.)

In numerical control, where accuracy is paramount, parity checks are frequently used as a safeguard against certain obvious errors which can arise; for instance, it can be stipulated that a digit must be represented by a combination of three holes—no more and no less—and if, in reading any line, the tape-reader discerns less or more than three holes, it shuts down. This obviously reduces the number of unequivocal combinations in an n-channel tape from its theoretically greatest value of 2^n (or 2^n—1 if the no-hole set is excluded).

Accordingly, there has been a tendency to use tape having a greater number of channels, particularly in the U.S.A., where 8-channel tape is now the national standard for all data-processing. The standard code proposed by the Electronics Industries Association (E.I.A.) is shown in Fig. 1.

International Telegraph Code typewriters have 26 type-bars, each bar carrying two characters in an upper- and lower-case arrangement, though the actual distinction may be between a numeral and a punctuation mark. The code is thus ambiguous.

Probably the best known code for 8-channel tape is the IBM-Flexowriter code. The Friden Flexowriter has 42 type-bars and may or may not have a shift key, so that this system may or may not be ambiguous. However, if ambiguity occurs, it is because of the desire to reduce the number of type-bars (and hence keys on the key-board) and not because of the number of combinations available from the 8 channels, i.e., 255. In fact, only 128 of the possible number of signs are, by convention, admissible, and the reading of any non-admissible sign operates a visual or audible alarm.

One way in which a tape code can be made more foolproof is to arrange the characters to be coded in groups which can be automatically recognized; for instance, all numerals might be punched in channels 6 and 7. This, however, is not easily arranged in an electro-mechanical machine, but can be achieved in a purely electrical machine such as the Eichner "Flexotronic". The question of automatic recognition of character groups has been studied by the "Data Processing in Production Engineering" Group of V.D.I., and the problem has been discussed by Simon and Möhlen[5], in whose paper some character-group codes have been suggested.

Another source of possible error is, of course, the transcription stage, where a human operator uses some form of teleprinter to convert "human" language into coded language on the tape. The accuracy of transcription will obviously vary, but the general level is one mistake in every 300 to 2000 characters transcribed[6]. Such mistakes can be very costly, and the use of a tape verifier or a tape comparator is usually well worth-while.

(3) R. C. Brewer: "The Automatic Control of Production Processes". *Cybernetica*, Vol. II, 1959, No. 2, p. 98.
(4) R. C. Brewer: "Numerically Controlled Machine Tools". *Engineering*, Vol. 189, June 24, p. 871.
(5) W. Simon and W. Möhlen: "Über die Anwendung von Fünf- und Achtspurlochstreifen zur Steuerung von Werkzeugmaschinen". *Werkstatt und Betrieb*, Vol. 94, No. 4, p. 186.
(6) D. Barker: "How Paper Tape Meets Computer Demands". *Automatic Data Processing*, May 1959.

CHANNELS 1	2	3		4	5	6	7	8	
				•			●		ZERO
●				•					1
	●			•					2
●	●			•		●			3
		●		•					4
●		●		•		●			5
	●	●		•		●			6
●	●	●		•					7
				•	●				8
●				•	●	●			9
●				•			●	●	A
	●			•			●	●	B
●	●			•		●	●	●	C
		●		•			●	●	D
●		●		•		●	●	●	E
	●	●		•		●	●	●	F
●	●	●		•			●	●	G
				•	●		●	●	H
●				•	●	●	●	●	I
●						●		●	J
	●					●		●	K
●	●							●	L
		●				●		●	M
●		●						●	N
	●	●						●	O
●	●	●				●		●	P
				•	●	●		●	Q
●				•	●			●	R
	●			•		●	●		S
●	●			•			●		T
		●		•		●	●		U
●		●		•			●		V
	●	●		•			●		W
●	●	●		•		●	●		X
				•	●	●	●		Y
●				•	●		●		Z
●	●			•	●		●	●	FULL STOP
●	●			•	●	●	●		COMMA
●				•		●	●		/
				•		●	●	●	+
				•				●	−
●	●	●		•	●	●	●	●	DELETE
				•					● END OF BLOCK
●	●			•	●				END OF RECORD
				•					TAPE FEED

SPROCKET HOLES

Fig. 1. The standard E.I.A. code for 8-channel punched tape

In using a tape verifier, the punched tape is placed in a tape reader coupled to the verifier. A second operator, working from the same "human" language manuscript, enters the data via the verifier keyboard. As long as there is agreement, a second tape (called the verified tape) is punched but, if there is any disagreement, the verifier keyboard becomes locked and can be freed only when the disagreement has been resolved.

Clearly, this method does not ensure a perfect tape, but it does raise the probability of perfection to an extremely high value.

If a tape comparator is used, two original tapes are required (preferably from two separate operators). These tapes are then passed through the twin-reader of the comparator, and a third tape is punched as long as the original two tapes are in agreement. Here again, any disagreement causes a shut-down.

Taking Creed equipment as an example, a tape verifier has a maximum speed of 16 characters per second, while a tape comparator can be somewhat faster at 26 characters per second. The latter, of course, is a real speed, since the process is automatic; however, verification involves a human operator, and it is most unlikely that the speed of 16 characters per second would be the limiting factor, particularly with an operator working over an appreciable period of time.

Turning now to tape reading, there have naturally been advances, both in basic ideas and, what is more important, in putting them into practice. The ordinary mechanical finger type of reader, such as the Creed Model 92, has a reading speed of up to 20 characters per second. This figure can be roughly doubled if the mechanical part is made more delicate and more sensitive, involving the use of trailing contacts and necessitating a unidirectional tape movement.

Pneumatic methods based on pressure differences have been known for many years, but reading speeds used to be slow. A more successful attempt to use pneumatic techniques has been borrowed from the hot-wire anemometer, in which a hot wire element is located under each channel of the tape, and the air current arising when a hole is present changes the temperature and hence the resistance of the hot wire. The reading speed, which can be quite good, is obviously dependent on the skill with which the variables (temperature drop, response time, etc.) can be balanced.

Optical methods were briefly mentioned in the previous survey, but have made great strides in the last few years. In view of the trend towards tape with more channels, the most interesting development from a cost point of view is the use of a scanning disc, similar to that in a television camera, to scan each channel of the tape successively. Only one photocell or phototransistor is now needed, instead of one for each channel.

Another development is the use of reflective, rather than transmissive, techniques. The tape passes over a pentagonal prism whose function is merely to act as an improved form of mirror, the photo-transistors having to differentiate the reflected light from the tape and that from the "mirror" (i.e., where a hole is punched). This reflective technique could be applied to opaque tape with printed spots instead of holes, provided that the reflective characteristics of the tape and spots can be resolved by the photo-transistors. Like semi-perforated tape, the advantage of a printed-spot tape is the ease with which the data can be put on the tape in "human" language, as well as in the coded form.

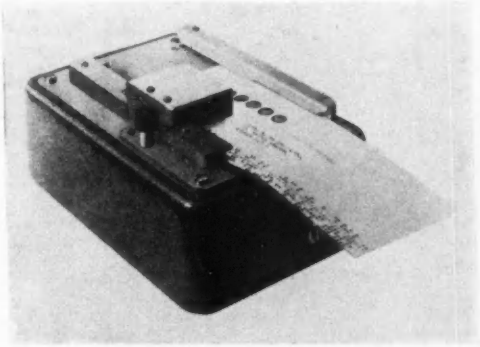


Fig. 2. An edge-punched card and reader.
(Courtesy of Creed & Co. Ltd.)

The use of optical techniques such as these has given tape-readers speeds up to 1000 characters per second and, until the frequency-response limit of photo-transistors is raised, there seems little possibility of any further increase. Such equipment, in any event, is obviously expensive.

One interesting hybrid medium is the edge-punched card shown in Fig. 2, in which a card is used but the data are punched, according to a punched-type code, along one edge of the card, the remainder of the card being available for printing the data in "human" language.

Transducers

In the previous survey, the general features and characteristics of transducers were discussed, and their application in particular positional and continuous contour control systems was described. In the present survey, it is therefore assumed that the principles of the more general transducers, such as diffraction gratings, synchros, etc., are understood and it is proposed to discuss here only recently developed transducers, without reference to their specific applications. An exception is, however, made in the case of the Belgian lathe described in the next part of this survey, because it seemed desirable to discuss this particular transducer with reference to its specific application.

For convenience, these new transducers have been classified in terms of (1) transducers based on capacitive action, (2) transducers using photo-electric or magneto-electric microscopes, (3) synchros or resolvers, (4) differential transformers, (5) mechanical transducers, (6) digitizers, and (7) optical gratings.

Transducers using Capacitive Action

Since the publication of the original survey, an interesting transducer has been developed by the Reilly Engineering Company. This transformer uses a differential capacitance pick-up to effect a continuous subdivision of the voltage steps obtained from an accurate voltage-dividing transformer. Physically, the static part of the transducer consists of a number of cylinders (stators), insulated from each other and assembled on a tie-rod under axial pressure. The actual length of each cylinder controls the magnitude of the fine resolution (the shorter the cylinder, the finer the resolution), while the accuracy to which the length is maintained governs the precision with which the coarse resolution is affected.

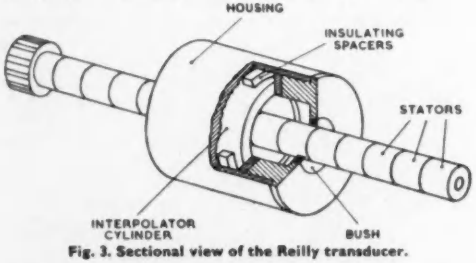


Fig. 3. Sectional view of the Reilly transducer.

The moving part of the transducer (Fig. 3) is a cylindrical housing which contains and shields the interpolator. The insulating bush shown in Fig. 3 is used to maintain a certain clearance between the housing and the stators, but it is unnecessary, even undesirable, to use such a bush if clearance is ensured by the method of attaching the parts to the machine tool (or measuring machine), especially since concentricity is not critical.

The interpolator is a cylinder of appreciably larger diameter than the stator cylinders, and it is the capacitive effect between the interpolator and the adjacent stators which provides the fine resolution. Fig. 4a shows schematically how the coarse and fine resolutions are obtained. The stator cylinders are connected to accurate linear tappings on a voltage-dividing transformer, this being the coarse resolution. If the axial length of the interpolator were very small compared with the length of the stators, then the output voltage V would vary with displacement x according to the "staircase" law shown in Fig. 4b.

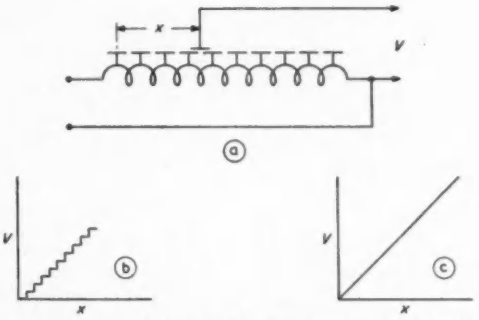


Fig. 4. Method of achieving fine and coarse resolution in the Reilly transducer.

The shortest stator manufactured by the Reilly Company is 0·25 in. in length, which is much too coarse as a resolution for machine-tool purposes. Consequently, the interpolator has a length which is equal to that of the stators and functions as a differential condenser with respect to the adjacent stator sections, thus giving the continuous linear relationships shown in Fig. 4c. In this way, the coarse resolution is divided in an analogue manner, and the fine resolution is clearly governed by the least voltage change which can be discriminated. If the output voltage were measured in the simple manner shown in Fig. 4a, resolution would be poor and, in any event, the potentialities for automatic functioning would be small.

If however, the voltage-dividing transformer constitutes two (unequal) arms of a bridge-circuit as shown

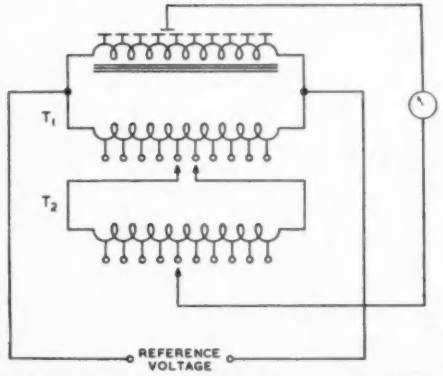


Fig. 5. Practical method of voltage measurement in the Reilly transducer.

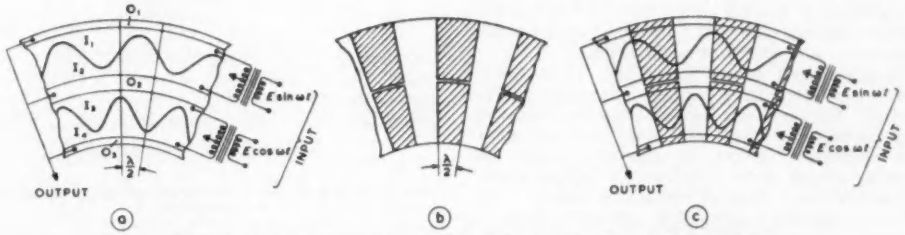


Fig. 6. Etched patterns on the elements of the Telecomputing Corporation transducer.

in Fig. 5, potential balancing techniques can be used. The transformer T_1 divides the reference voltage into ten equal steps, while the second transformer T_2 is connected across one step of T_1 and thus divides the reference voltages into hundredths. For simplicity, only two transformers are shown in Fig. 5, but it will be evident that, in any practical system, the number required will be equal to the number of digits demanded by the total length of movement and the resolution; thus, 99·999 in., subdivided down to 0·001 in., would require five transformers.

The transducer can be used manually by setting the transformer decade switches to the command position and moving the interpolator until balance is achieved, or *vice versa*. However, the output from the bridge circuit gives not only the magnitude of the unbalance, i.e., error voltage, but also its sense, so that it can be used to drive a servo-motor. The use of a bridge circuit facilitates the injection of a known voltage to effect a zero offset.

Another transducer which uses electrostatic or capacitive coupling is that developed by the Telecomputing Corporation, the essential elements being two circular glass discs, one of which is fixed and the other either attached or coupled to the moving member. The discs are located coaxially with a small (axial) air gap between them. Fig. 6 shows the metallic patterns on the surfaces of the two discs, these patterns being produced by standard photo-etching techniques. It will be seen that, on the fixed disc, there are input and output channels (Fig. 6a). The input channels consist of two annular conducting rings, each divided circumferentially by an insulating "strip" which has sinusoidal waveform with an angular wavelength λ. These four conducting areas (I_1 to I_4 in Fig. 6a) form two sinusoidal patterns which are 90 deg. out of phase with respect to each other. The output channels are simple conducting annuli (O_1, O_2, and O_3). The moving disc (Fig. 6b) has a pattern consisting of sectors subtending an angle of $\frac{1}{2}\lambda$. Fig. 6c shows the two discs superimposed.

The input channels are connected to voltages of equal magnitude, but 90 deg. out of phase. The pattern on the moving element is not connected to any external electric circuit but merely acts as a (variable) capacitive coupling between the input and output channels. The voltage between the output channels and earth is, in fact, the vector sum of the four coupled voltages and, although constant in magnitude, varies in phase, its phase angle at any instant being uniquely related to the position of the moving disc.

This is an extremely sensitive system of fine positioning (it has been used in a theodolite) but, for coarse positioning, another set of patterns is deposited on the discs. To avoid interference between the two positioning systems, different exciting frequencies are used. This transducer has the advantage of resolving to about 1 in 200,000, and is unaffected by local irregularities, but the input voltages must be accurately in quadrature and as devoid of harmonic distortion as possible.

Photo-Electric or Magneto-Electric Microscopes

The coarse-positioning device developed by Minneapolis-Honeywell is rather unusual in its physical conception. The table element is a metal scale having ten undulatory tracks in which the rises and falls follow a binary coding. The fixed element is a housing containing ten precision limit-switches which follow the rises and falls of the scale tracks. Thus, these limit-switches give an output which uniquely defines the table position in binary form ; in principle, the coarse transducer is a linear form of digitizing disc with a rather more elaborate system of making electrical contact. The fine transducer is effectively a photo-electric microscope with an electrical resolution of 0·001 in.

The transducer developed by Hughes Aircraft for the quill movement of the Burgmaster turret drill is a magnetic analogy of the photo-electric microscope. A metal scale (14 in. long in this case) has a series of engraved lines like a conventional line standard, a magnetic detector moving along the scale giving an a.c. output with peaks every 0·002 in. An increase in resolution to 0·001 in. can be effected by using two detectors spaced at an odd number of quarter wavelengths.

Resolvers

The Farrand "inductosyn" has been described in the previous survey, but mention should be made of the new "multi-speed" inductosyn, in which two coarse windings are superimposed on the fine winding. As a result, the inductosyn is now not restricted to the 0·05 in. range, which was formerly its limit if ambiguity was to be avoided.

Differential Transformers

The American Company, W. F. and John Barnes, has introduced a novel variant on the transformer type of transducer. To understand its principle, consider a long tubular core carrying a centre-tapped winding, the ends of which are connected to one side of the line voltage and the centre-tap to the other. If a short secondary coil of slightly larger diameter is now moved concentrically along the first winding, the voltage induced will be constant in most positions but, near the centre-tap, the phase will change by 180 deg. In the vicinity of the centre-tap, then, the phase is an analogue of the position of the secondary winding and will act as a fine transducer with a resolution of about 0·001 in. Coarse positioning is achieved in practice by tapping not just the centre point, but a series of points at 1-in. intervals. These tappings are brought out to the contacts

of a multi-way switch, the heel of which is connected to one side of the line voltage. Coarse positioning (manual or automatic) is thus effected by the switch.

In the original survey, the B.T.H. (now A.E.I., Rugby) and Pratt and Whitney transducers were described. Both of these used an alternating magnetic/non-magnetic pattern for coarse positioning and servo-driven micrometer screws for fine positioning. An interesting variant on the micrometer technique is used in Gisholt's own "Factrol" system of control. The main measuring bar consists of an alternation of north and south magnetic poles at an accurate pitch. The pick-up head consists of a square-threaded screw of Permalloy coupled by a Permalloy core to the pick-up coil, as shown in Fig. 7. The screw is driven by a synchronous motor at a speed such that the axial velocity of the screw relative to the bar is 120 pitches/sec, inducing in the coil a voltage of 120-cps frequency whose phase φ is an analogue of the relative displacement of the screw and bar. In this way, the coarse resolution (the pitch of the magnetic poles) is sub-divided in an analogue manner.

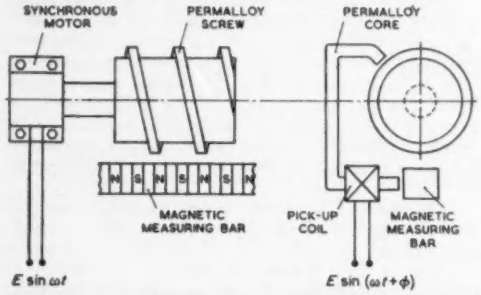


Fig. 7. Diagrammatic representation of the Gisholt transducer.

For its new positioning System, the Société d'Electronique et d'Automatisme has developed an electromagnetic transducer for fine resolution. Attached to the machine table is a measuring bar which is toothed or castellated with pitch p, as shown in Fig. 8. The sensing element consists of three coils wound on a split core, the two lower ends of the core being also castellated; the right-hand castellation is spaced at an odd number of half-pitches from the other. Consequently, when coil C_1 is energized by an alternating current, the voltages induced in coils C_2 and C_3 are proportional to $\sin(2\pi x/p)$ and $\cos(2\pi x/p)$, where x is the displacement from any position in which zero voltage is induced in coil C_2. In this way, an anologue subdivision of the coarse resolution of 2mm is effected, while a fine resolution of 0·01 mm is claimed.

Mechanical Transducers

A mechanical transducer used by Warner and Swasey employs a pawl mechanism for coarse positioning but, being based on mechanical contact, is unsuitable for continuous control systems. Fig. 9 shows the arrangement of the transducer in its linear form, although it is equally suitable for rotary operation. The moving element *A* carries a series of pins at accurately spaced intervals. The fixed element is a base-board *B* carrying a guide *G* on which the pawl-slide *S* can reciprocate. This pawl-slide carries a hinged pawl *P* which can be held against any given pin or retracted by the action of a solenoid *E*.

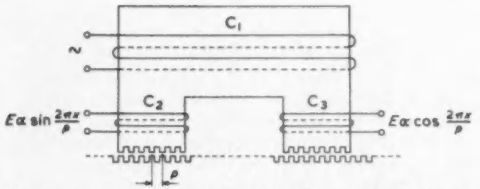


Fig. 8. The transducer of the Société d'Electronique et d'Automatisme.

During rapid table traverse, the pawl is retracted, and a synchro-monitored drive positions the table to the nearest pin (i.e., coarse positioning). Final positioning at creep speed is always a downward movement (for the arrangement shown in Fig. 9), and, at the commencement

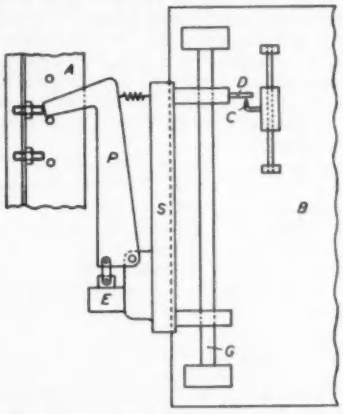


Fig. 9. Diagrammatic representation of the Warner & Swasey pawl transducer.

of this movement, the pawl is forced into contact with the nearest pin. Contact is maintained as the pin moves downward by driving the pawl-slide through a slipping clutch (not shown). This movement continues until the dog *D* on the pawl-slide touches the contact *C*, after which the table drive ceases and the table is clamped. The contact *C* can move along its slide and is positioned by a motor-instrumentation system so as to divide the pitch of the pins in the required interval, thus effecting fine positioning. The resolution demanded of the synchro is of the order of 1 in 250 to 500, while that of the fine-positioner is 1 in 1000 to 2000 — both quite reasonable values.

Digitizers

Recently, there have been developments in digitizing or coded discs, mainly in the direction of increased resolution. A simple binary-coded disc having n zones will resolve one revolution into 2^n parts, and one American manufacturer is reported to be offering an 18-zone disc, which can subdivide the revolution into 262,144 parts, i.e., into intervals of slightly less than 5 sec. The generally accepted limit is, however, $2^{16} = 65{,}536$ (almost 20-sec intervals), but there is much to be said for using the digitizing disc in conjunction with another transducer, in which case a division of $2^{10} = 1024$ would be convenient for a binary-coded disc and a division of 1000 for a decimal-coded disc. Interest in cyclic codes (which were discussed in the previous

survey) is definitely increasing as more accent is placed on reliability.

Linear forms of digitizing disc are now available but, for the pattern accuracies of interest in the machine-tool field, it is very difficult to join digitizing scales end-to-end, so that a limitation is imposed on the maximum length of scale (from 2 to 3 ft).

More recently, there has been a greater success in making magnetic digitizers. The coded disc is ultrasonically or spark-machined from a solid ferrite blank, the pattern being formed from segments of two thicknesses—the original disc thickness or the reduced thickness where the disc has been machined. The coded disc forms part of a magnetic circuit (Fig. 10), which also includes the casing (a core excited by a fixed field coil) and a ferrite-cored sensing coil fed from an a.c. source in such a way that the polarities of the two fields are in opposition.

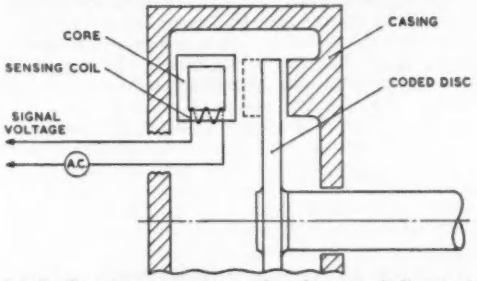


Fig. 10. Diagrammatic representation of a magnetically sensed digitizing disc, the broken line adjacent to the coded disc representing the thicker section.

It will be seen that the voltage induced in the sensing coil will depend on how completely the air gap is filled by the ferrite disc. When the full thickness of the disc is in the air gap, the weakening effect of the fixed field is at its greatest, and the induced voltage is very small. On the other hand, the thinner sections of the disc will not have such a weakening effect, and an appreciable voltage will be induced, the actual magnitude depending on that of the exciting voltage, with some waveform distortion. Nevertheless, the device is obviously bistable, and the two states may be designated "zero" and "one", corresponding to "transparent" and "opaque" in the optical digitizer.

Optical Gratings

The Staveley Research Department has developed a very neat method of using coarse optical gratings (of, say, 100 lines per inch) to obtain a resolution of about 0·0002 in. An earlier version of this transducer has been described by Davies *et al*,[7] but there have since been some changes, the most important being the adoption of a reflective, rather than a transmissive, principle, and the parallel alignment of the grating lines. This latter change means that the optical system does not now rely on Moiré fringes.

Clearly, the counting of lines will yield a resolution of only 0·01 in., and this is, in fact, the coarse resolution of the system. Fine resolution is effected by a phase-modulating technique employing four photocells (silicon photo-voltaic diodes) spaced at intervals equal to one-

(7) B. J. Davies, R. C. Robbins, C. Wallis, and R. W. Wilde: "A High-Resolution Measuring System using Coarse Optical Gratings". *Journal IEE*, Vol. 107, Part B, p. 624.

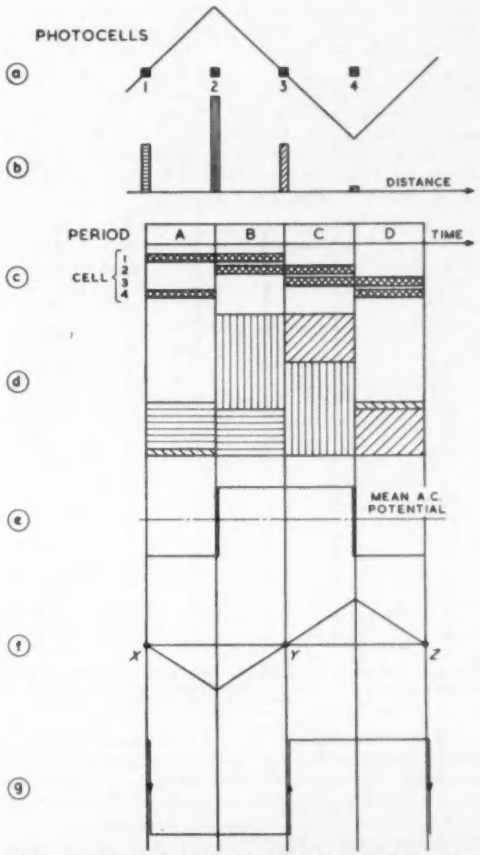


Fig. 11. Production of the phase-modulated signal in the Staveley transducer.

quarter of the grating pitch. The intensity of illumination over a length equal to one pitch of the grating is approximately triangular, as shown in Fig. 11a. Accordingly, the photocell currents are as shown in Fig. 11b, the current in photocell (2) being a maximum and that in photocell (4) a minimum. The abscissa in both these figures represents distance along the grating. The photocells are switched in and out of the measuring circuit by electronic switching driven from an a.c. source, so that the current from each photocell is monitored for only half of each cycle, the periods being shown by the bar chart in Fig. 11c. It should be noted that the abscissa in Figs. 11c to 11g represents time, although the time interval is so short that, during the complete period shown, the photocell currents may be assumed to be constant at the values shown in Fig. 11b.

During each period of time, the monitored photocell currents are shown in Fig. 11d, and their sums, together with the mean a.c. potential, are indicated in Fig. 11e. The sum of the photocell currents is then integrated electronically to give the pattern shown in Fig. 11f. The zero points *X*, *Y*, *Z* are important, because they define the times at which the rising and falling edges of the squared wave (Fig. 11g) occur. The rising edge is, in fact, used for phase measurement, and moves with the

travel of the table grating. It might be wondered why the square wave in Fig. 11e has been integrated, only to be squared again, as in Fig. 11g. The answer is that, for simplicity, Fig. 11 has been drawn for the grating position where photocell (2) has maximum current; at the next switching cycle, the table has moved and a different grating position is sampled. Fig. 11e would then not be a square wave but a more complex pattern of straight lines, as shown in Fig. 12, in which (e), (f), and (g) correspond to Figs. 11e, f, and g.

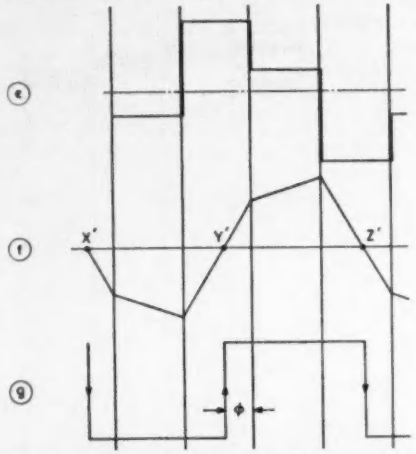


Fig. 12. The effect of changed grating position on the phase-modulated signal in Fig. 11, φ signifying the phase change from time in Fig. 11.

When the table moves with a constant velocity v and the switching frequency is f, there is a phase error per switching cycle which, although having an average value of zero over a time equal to the lowest common multiple of $1/f$ and $1/(f+v)$, changes in magnitude and sign within this period. An experimental investigation into a contouring system with v in the range of $\pm 0{\cdot}4\,f$ did not show any errors due to phase which were comparable with the 0·001-in. mechanical error expected from the machine.[7]

Machine-Tool Elements

The machine-tool elements in which major developments have taken place since the previous survey are circulating ball nuts, hydrostatic drives, and bearings. It is thus proposed to review the present position regarding these elements.

The circulating ball nut contains a stream of precision balls which circulate continuously when there is any relative movement between the nut and screw. Thus, the sliding friction of the conventional nut and screw is replaced by rolling friction, with a consequent improvement in efficiency. Indeed, most ball nuts have efficiencies between 90 and 100%.

Ball nuts may be simple or preloaded, the latter type being of particular interest for machine tools, since it is specifically designed to control backlash. Ball nuts minimize stick-slip, i.e., they permit very small movements to take place in a continuous manner, thereby increasing the stiffness which the machine tool contributes to the closed servo-loop.

The commonest type of preloaded ball nut is the double nut. With this type, the amount of preloading is obtained by the use of a shim placed between the flanges of the nuts, the thickness of the shim giving the required amount of preloading; if any subsequent adjustment is necessary, the shim can be replaced by a thicker or thinner shim. Such ball nuts are inherently completely reversible and, if irreversibility is required, special steps must be taken to achieve it.

The life of a ball nut (in inches of travel) is affected by the load according to an approximate cube law, and the rated load is usually based on some specific life; for example, Bristol-Siddeley base their rated load on 10^6 in. of travel.

Interest in the hydrostatic drive has increased considerably in the last few years for both aircraft and machine tools, the latter benefiting from research done specifically for the former. A hydrostatic drive consists of a pump and a motor, both of the positive-displacement type; these elements can be located at a considerable distance from each other. Their power/weight ratio is much higher than that of an electrical drive, so that accelerations (including those associated with change of direction) are effected more easily.

The use of hydrostatic drives in machine tools permits the elimination of gear-trains and facilitates the provision of constant cutting speed in facing cuts. Accordingly, when the National Engineering Laboratory decided to investigate the potentialities of the hydrostatic drive for machine tools, a boring mill was chosen as the first machine to be studied.[8]

Machine-tool bearing surfaces in general have been the sources of frictional losses, stick-slip, and non-linearities, all of which should ideally be eliminated in a numerically controlled machine tool. Interest has centred mainly on bearings in which a film of a lubricating liquid or a gas (e.g., air) of finite thickness separates the bearing surfaces. Bearings using a lubricating liquid are usually termed hydrostatic bearings to distinguish them from air bearings.

It might be thought that a bearing in which the opposing surfaces are separated by a fluid would be the antithesis of the high dynamic stiffness required in a servo-monitored machine tool. It has, however, been shown by Brown[9] that hydrostatic bearings are not detrimental to the dynamic characteristics of a machine-tool structure.

The hydrostatic bearing can be represented by the equivalent spring-and-damper system shown in Fig. 13, in which k_s represents the static stiffness of the bearing, which is strictly not constant but which may be assumed to be constant, since the analogue is of use mainly for studying dynamic behaviour, where the amplitude can be taken as small. The dynamic response of the bearing is represented by the spring k_d and the damper c_d. The effective stiffness is naturally complex, and in Fig. 14 the variation of stiffness with frequency is shown in terms of the real (in-phase) and imaginary (quadrature) components of stiffness.

From his experimental investigations, Brown[9] concluded that the analytical approach using an equivalent system was justified, at least qualitatively. For simplicity, Brown's equivalent system placed the static

(8) D. FIRTH: "Hydrostatic Drives for Machine Tools". *Engineering*, Vol. 189, June 17, p. 827.
(9) G. M. BROWN: "The Dynamic Characteristics of Hydrostatic Thrust Bearing". Paper presented at the First International Conference of Machine Tool Design and Research, Birmingham, 1960.

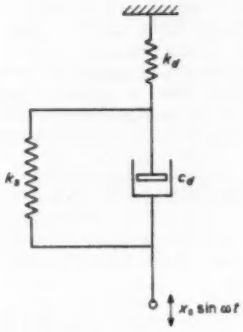


Fig. 13. Equivalent spring-and-damper system for a hydrostatic bearing.

spring stiffness k_s across both k_d and c_d, which is probably justified since k_s is usually much smaller than k_d. It will be noted that the equivalent stiffness of the bearing will be higher under dynamic conditions, since the in-phase stiffnesses k_s and k_d are additive. The damping effect due to c_d is a function of the applied frequency and reaches a maximum value at a specific frequency, as shown in Fig. 14.

In the U.K., a considerable study of air bearings has been made by the National Engineering Laboratory, firstly in a general fundamental way and, more recently, with a specific view to their application in measuring machines and machine tools. Investigations into flat-pad bearings under static conditions have suggested that the ultimate load which a bearing can carry is proportional to the air pressure and bearing area and is related to the dimensions of the orifice pocket in a more complex way. Also, it appears that the bearing stiffness is inversely proportional to the diameter of the orifice, but is sensibly independent of the air pressure, at least in the range tested.

As with hydrostatic bearings, interest in air bearings must also centre on dynamic performance, if application to machine tools is envisaged. Tests have shown that the relationship between dynamic stiffness and frequency is virtually the same as that pertaining to a mass/spring system having the same mass and stiffness; in other words, the resonant frequency of an air bearing is governed by the same equation as that for a single mass suspended from a spring.

In the case of a milling-machine table designed to have its weight of 500 lb supported by two pads, each 31·5 in. in length and 1·5 in. in width, it is reported[10] that, using an air pressure of 60 psi, the pads supported a load of 1250 lb and had a static stiffness of $1{\cdot}3 \times 10^6$ lb/in. It would therefore appear that the natural frequency is appreciably higher than any forcing frequency due to the milling operation, and thus dynamic stiffness would not be much greater than static stiffness. However, experiments are in progress to investigate the response under actual cutting conditions.

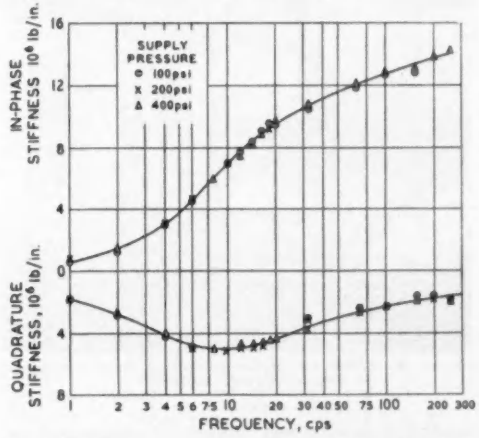


Fig. 14. Variation in stiffness of a hydrostatic bearing with frequency.

Much work remains to be done on air bearings, but it is encouraging to note the success with which they have been applied to measuring machines, particularly to the National Engineering Laboratory roundness-measuring machine.

POSITIONAL CONTROL SYSTEMS

Recent British Developments

In the U.K., there has not been the spectacular increase in the number of positioning systems that has characterized the American scene. It would be easy to conclude that the interest displayed by the British machine-tool user is much less than that of his American counterpart; yet, although there are no published figures for the total number of controlled machines in Great Britain, a rough estimate shows that, allowing for the population ratio, the situations in the two countries are not of a markedly different order.

The author feels that the position is better summarized by saying that there are two groups of control-system manufacturers in this country, i.e., active and passive. To the best of his knowledge, Brush as well as Hilger and Watts, have not sold a control system, although both hold patents for a positioning system and would presumably be prepared to make and sell if approached. Also the Ericsson company has withdrawn from the field of numerical control, at least for the time being. On the other hand, most of the remaining British companies mentioned in the previous survey are actively engaged in making and selling the systems described—systems which have proved satisfactory and have needed little in the way of modification during the last two years.

As an example, the Airmec "Autoset" has been changed only to the extent of providing two optional extras, i.e., an additional switch at the fine end, giving increments of 0·0002 in., and an additional switch at the coarse end to give increments of 100 in. Fig. 15 shows an application of the Autoset to a Wadkin moving-bridge

(10) H. L. WUNSCH: "The Design of Air Bearings and their Application to Measuring Instruments and Machine Tools". Paper presented at the First International Conference of Machine Tool Design and Research, Birmingham, 1960.

machine, as used by Richardsons Westgarth for drilling plates up to 14 × 20 ft. In view of the large and expensive workpieces involved, two Autosets are used, their positioner units being ganged on the leadscrews. The first unit controls movement in the normal way, while the second acts as a safety-monitor, since drilling cannot commence unless the brushes in the second unit are at rest in the dead sectors of their commutators. This arrangement covers both malfunction in one of the Autosets and errors in punching the tape—at least to the extent that it is most improbable that the same error would occur in both systems (or both tapes) at the same time. It will be recalled from the previous survey that the Airmec system uses a special tape, so that the standard proprietary tape verifiers and comparators are of no use. The use of a second control system to monitor the first appears to be rather a luxury and is presumably only feasible because the Autoset is so modestly priced.

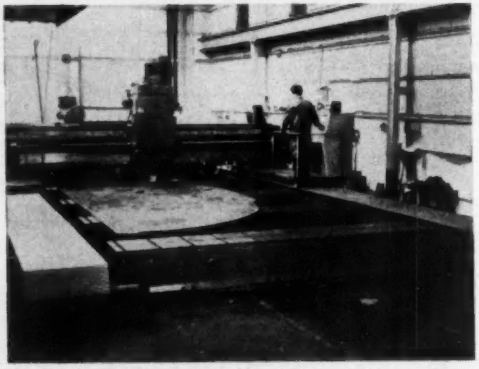


Fig. 15. A Wadkin moving-bridge drilling machine equipped with two Airmec "Autosets".
(Courtesy of Airmec Ltd.)

The De Vlieg "Spiramatic" jigmill with "Datatrol" positioning system is now being built in the U.K. under licence by Alfred Herbert Ltd. Storage can be temporary (decade switches) or permanent (8-channel punched tape). The control system is analogue and is based on the inductosyn as the transducer, the error signal from which is rectified and used to control a d.c. motor which acts as the servo-drive.

A new positional control system using the optical transducer previously described has been developed by the Staveley Research Department and is manufactured by W. H. Smith (Electrical Engineers) Ltd., for use on a boring machine made by George Richards & Co. Ltd. All three of these organizations are members of the Staveley Group of Companies. Normal input is by decade switches, but a tape-reader for 5-channel punched tape is an optional extra. The information withdrawn from the buffer store follows two closed loops, one of which is for coarse positioning and the other for fine positioning (Fig. 16). Both loops, however, use the same transducer, which, in this application, derives its switching frequency signal from a local oscillator.

Coarse resolution is effected by counting the number of complete cycles of phase change in the output from the transducer, each cycle corresponding to 0·01 in., i.e., the pitch of the lines in the grating. A transistor ring counter is used for this purpose and is coupled to a decimal read-out, so that a visual display of the position is available. The cycles of phase change are compared with the coarse positional information from the buffer store and, if there is any coarse-error signal, the servo-motor is actuated but not controlled (i.e., it runs freely) until the final position is approached. The inertia of the table naturally causes an overshoot, and an auxiliary counter is added to effect coarse return over a few cycles. When the count is down to one cycle, the fine-positioning loop is switched in, effecting continuous control over the servo-motor until the final position is reached.

The fine-positioning feedback signal is the phase change within one cycle and is consequently analogue. A converter is clearly needed at some point in the fine-positioning loop, and Staveley decided to convert the fine digital information from the buffer store into analogue form and make a phase comparison. In the particular application mentioned (the Richards boring machine), positioning is sequential, because there is only one drive motor, though this is not an inherent feature of the system.

E.M.I. Electronics Ltd. have introduced a new positional control system in which sequential movement of the table is deliberately incorporated. Many components were studied, and it was found that a surprisingly high percentage of movements involved a change in only

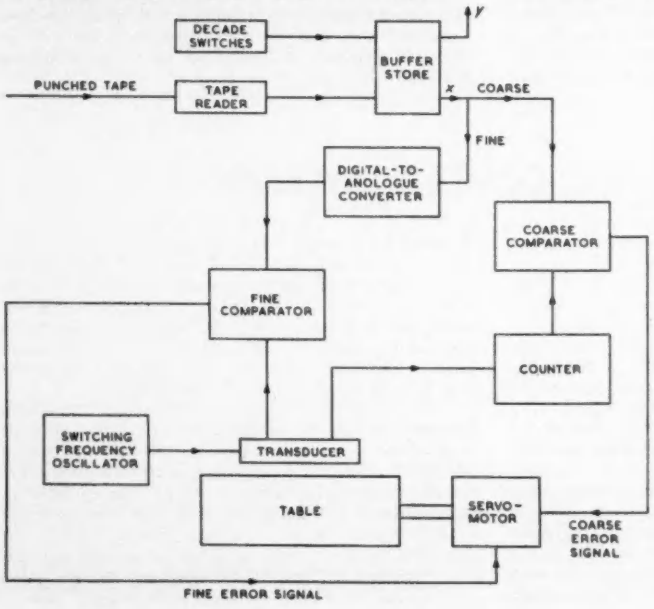


Fig. 16. Block diagram of the Staveley positional control system.

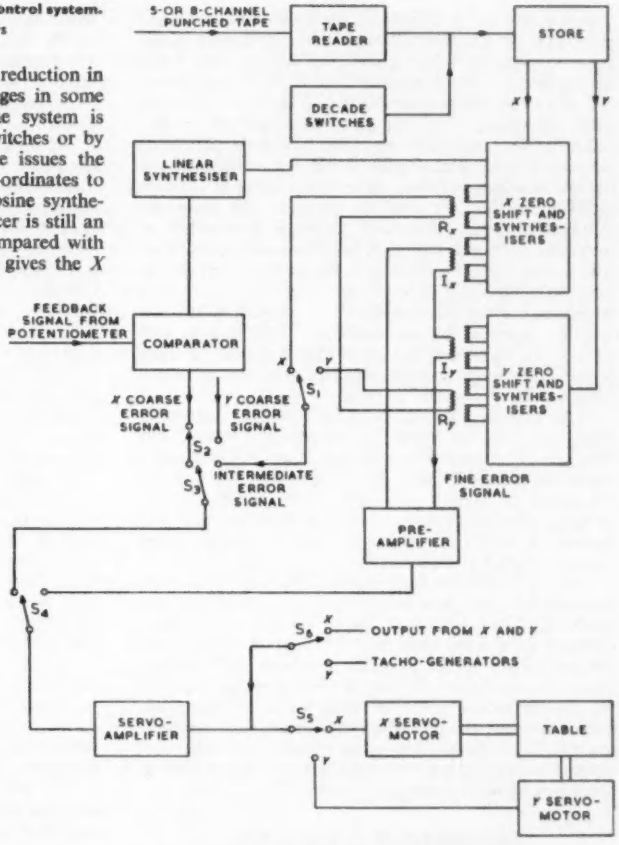


Fig. 17. Block diagram of the E.M.I. positional control system. Ix and Iy inductosyns; Rx and Ry resolvers

one co-ordinate. This, together with some reduction in price, was felt to outweigh the disadvantages in some circumstances. The block diagram of the system is shown in Fig. 17. Input is by decade switches or by 5- or 8-channel punched tape. The store issues the numerical information for the X and Y co-ordinates to the X and Y zero-shift circuits and sine-cosine synthesisers. For coarse positioning, the transducer is still an inductor potentiometer whose output is compared with the signal from a linear synthesiser. This gives the X and Y coarse-error signals, the relevant signal being selected by switch S_2.

The intermediate transducers are again resolvers fed simultaneously with sine-cosine voltages from the intermediate synthesisers. Because of this simultaneous excitation, switch S_1 is needed to select the X or Y intermediate-error signal, as required. As in the previous system, switch S_3 passes control from the coarse- to intermediate-error signals at about 3 in. from the final position.

The fine transducers are inductosyns and, since they are excited sequentially, the rotors can be permanently connected in series, the output being the fine-error signal. After amplification, the fine-error signal is fed to switch S_4, which passes control from the intermediate-error to the fine-error signal when the final position is almost reached (say, within 0·05 in.). Owing to this gradual transfer of control, the servo-amplifier is saturated during the main part of the traverse (the servo-motor running freely) and only in the final stages of positioning does the amplifier output exert any control on whichever servo-motor has been selected by switch S_5. In order to control the speed during final positioning, the output voltages from the X and Y tacho-generators are switched into the output from the servo-amplifier.

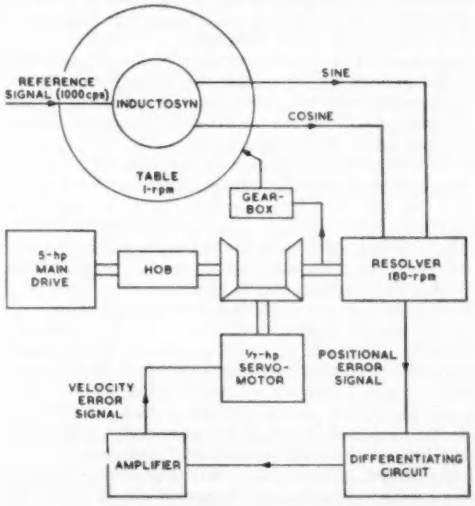


Fig. 18. Block diagram of the E.M.I. control system for a gear-hobbing machine.

The most interesting innovation, however, is the introduction of an addressed system of commands, by means of which all commands, numerical or functional, are preceded by a code symbol which routes them to the appropriate store circuitry. Thus, a system designed for a centre lathe is easily adapted for a turret lathe merely by adding a store for the turret and specifying a code symbol which will route turret commands to this store. A great measure of flexibility in meeting machine-tool builders' requirements is thus conferred on the system. The system can function entirely automatically, or movements in the third dimension, e.g., drilling, can be initiated manually. When using manual input, the X and Y co-ordinates are set up sequentially, an X-Y selector switch being provided.

Another interesting E.M.I. development is a control system for a gear-hobbing machine which will now be briefly discussed, although it is somewhat difficult to classify it as either positional or continuous contour control. Typical speed and power figures have been added to the block diagram in Fig. 18. When the hob is cutting a gear on the table, there must be a precise and

constant velocity ratio between these two elements if the gear is to be accurate. Owing to imperfections in the gears coupling the hob and table, this velocity ratio is not maintained at a constant value, and it is the function of the control system to improve the accuracy of the hob/table reduction. For this purpose, a 360-pole rotary inductosyn is attached to the table, its sine-cosine voltage output being the table position (relative to some arbitrary datum) in analogue form. This output is fed to a 2-pole resolver, so that the resolver speed is 180 times the inductosyn speed; since the degree is subdivided in multiples of 60, this 180 : 1 reduction is very convenient. The output from the resolver is the positional error but, since it is the ratio of velocities which has to be held constant, a differentiating circuit is inserted before the amplifier feeding the servo-motor. This servo-motor has a power equal to about 2% of that of the main driving motor and merely inserts the correcting velocity via a differential, as shown.

The current Ferranti positional control system is essentially that described in the previous survey, but alternative storage media, using 5-, 7-, or 8-channel tape, are now available. These, of course, would not have the advantage of needing no buffer store, but the block-reading, which was a feature of the original design of this system, required a non-standard code, thus necessitating a special punch and reader.

With the present system, the table approaches the commanded position at a fast speed and, slightly before reaching it, the magnetic clutch of the servo-motor switches to a creep drive in the reverse direction; the intertia of the table, however, is always sufficient to cause it to overshoot, so that final positioning occurs in the reverse direction and at creep speed. Ferranti are prepared to offer an anticipatory system for final positioning (i.e., non-overshooting) as an optional alternative for users who have strong views on whether final positioning should include an overshoot or not.

Developments in the U.S.A.

Last year, at the Chicago Exposition, at least 14 new American systems were exhibited. There are, in fact, so many new systems that a survey carrying a full discussion of them would be as long as, or longer than, the original survey. Accordingly, it has been decided to discuss in this section the more unusual and/or interesting developments in the field of positional control, and these are included in Table I, which summarizes recent positional-control systems from various countries.

One of the biggest names in the American control field, Minneapolis-Honeywell, has extended its activities to include numerical control, entering the field with a 3-axis positioning system for the Famco 200 vertical milling machine. The special system used for coarse positioning has already been described in the previous section. The fixed part of the fine transducer is a polished metallic scale ruled with lines at 0·1-in. intervals. The moving part contains a light-source and a suitable optical system for directing the light onto the scale, the reflected light being passed through a chopper and impinging on a photocell. The amount of light falling on the cell is a function of the relative position of the moving and fixed elements, and a resolution of 0·0001 in. is claimed.

The Norden Company has produced a system which is similar to that discussed in the previous survey, but is analogue rather than digital. The transducers are special linear-output synchros known as "Decasyns", which mainly differ from ordinary synchros in that they produce a triangular or saw-tooth wave instead of a sinusoidal wave. The system is applied to the Lapointe special rotary machine for drilling, tapping, reaming, and boring holes.

At one stage in the development of continuous contour control, it seemed almost a matter of course that the first of any new system should be applied to the Cincinnati "Hydrotel". In the realm of positional control, the corresponding machine is the Burgmaster turret drilling machine, which can be purchased with any one of ten control systems (including one British and one German). One of the most recent American systems is that developed by the Industrial Division of Hughes Aircraft. This system uses its conventional optical digitizing discs for sensing the co-ordinate movements of the table and, for the quill displacement, the magnetic measuring-bar system previously described was specially produced. An interesting feature of the quill control is the use of two electronic counters, one of which is programmed for the full hole depth and the other for an intermediate depth at which, say, slow feed begins during the downward movement. Another Burgmaster control system is from a newcomer to the numerical control field—the Rheem Manufacturing Co. The transfer medium is 8-channel punched tape which is read at 100 lines/sec. The transducers are magnetic digitizers working on the basis of impedance changes but, by the use of two magnetic heads, direction can be discriminated. The resolution of the transducers is, however, dependent on positioning speed, being 0·0001 in. at 120 ipm and 0·001 in. at 200 ipm.

Several systems using the inductosyn as a fine transducer are listed in Table I, including Farrand's own system, which employs the new coarse/fine inductosyn described in the previous section.

Unusual features of the Heald numerically controlled indexing fixture are the use of the rotary form of diffraction grating, a rather limited way of specifying the command information and the numerical code employed. With this system, one revolution can be subdivided into any integral number of equal angular movements from 2 to 99, but no other numerical information can be processed. The counter circuitry is based on binary-coded octenary system, rather than on the more normal binary-coded decimal system, and is claimed to simplify the circuits with its rather specialized manner of presenting command information.

The Warner and Swasey system, applied to one of their own turret lathes specially designed for numerical control, can be used as either a positional or a continuous contour control system. Digital in nature and using binary coding, its most interesting feature is undoubtedly the fact that the whole tape is run through the tape-reader before any machining takes place. Obviously, a fairly elaborate form of storage is needed and, in fact, the system uses a magnetic-core type of memory having a 96×96 matrix of cores; thus, up to 96 numerical instructions can be stored and each can be up to 96 binary bits in length. The functions over which control is effected are the spindle speed (in magnitude and sense), the feed rates of each turret in directions parallel and perpendicular to the spindle axes, and the selection of the turret station. In addition, the co-ordinate motions of the turrets are correctly synchronized so that the resultant turret movement is a straight line.

The great advantage of the type of memory used is

TABLE I: SUMMARY OF RECENT POSITIONAL CONTROL SYSTEMS

Manufacturer	Typical Application	Storage Medium		Transducer
		Permanent	Temporary	
Reliance, U.S.A.	Drilling machine	8-ch PT	DS	SYNCHROS
Sperry, U.S.A.	Wiedemann drill	8-ch PT	—	
Jones & Lamson, U.S.A.	Turret lathe	8-ch PT	—	
Norden, U.S.A.	Hole positioner	8-ch PT	DS	
Siemens-Schuckert, Germany	Drilling machine	—	DS	
Heller, Germany	Drilling and milling machines	5-ch PT	—	OPTICAL GRATINGS
Heald, U.S.A.	Indexing table	—	DS	
Tech. Hochschule, Aachen, Germany	Radial drilling machine	5-ch PT	—	
Staveley, England	Horizontal boring machine	5-ch PT	DS	
Hughes Aircraft, U.S.A.	6-spindle turret drill	8-ch PT	—	OPTICAL DIGITIZING DISCS
Warner & Swasey, U.S.A.	Turret lathe	8-ch PT	—	
Brown Boveri, Switzerland	Vertical milling machine	8-ch PT	—	
Erni, Switzerland	Vertical lathe	80-ch PT	—	
Renault, France	Drilling machine	8-ch PT	DS	
Svenska Aeroplan A.B., Sweden	Vertical milling machine	5- or 8-ch PT	DS	
Scharmann, Germany	Drilling machine	—	Hand-positioned synchros	ELECTRO-MECHANICAL DIGITIZING DISCS
S.E.L., Germany	Vertical milling machine	5-ch PT	—	
E.M.I., England	Turret drill	5- or 8-ch PT	DS	INDUCTOSYN
Giddings & Lewis, U.S.A.	Turret lathe	8-ch PT	DS or TD	
Allen-Bradley, U.S.A.	Drilling machine	8-ch PT	—	
Farrand Controls, U.S.A.	Drilling machine	8-ch PT	—	
De Vlieg, U.S.A.	Jig-borer	8-ch PT	DS	
Minneapolis-Honeywell, U.S.A.	Vertical milling machine	8-ch PT	—	OPTICAL SCALE AND MICROSCOPE
Société Genevoise, Switzerland	Jig-borer	8-ch PT	DS	
Rheem, U.S.A.	Burgmaster turret drill	8-ch PT	TD	MAGNETIC DIGITIZING DISCS
W. F. & J. Barnes, U.S.A.	Drilling machine	—	DS	DIFFERENTIAL TRANSFORMER
Gisholt, U.S.A.	Lathe	7-ch MT	DS	MAGNETIC MEASURING BAR
Contraves, Switzerland	Drilling machine	5-ch PT	—	DIFFERENTIAL CONDENSER
Ateliers GSP, France	Automatic tool-changing machine	10-ch PT or 35-mm film	—	MEASURING BAR
Centre National de la Recherche Scientifique, France	Drilling machine	Perforated-paper cylinder	—	CONTACT-DRUM REVOLUTION COUNTER
ACEC, Belgium	Taper-turning lathe	32-ch PT	—	SPECIAL SYNCHRO

ch = channel. PT = punched tape. MT = magnetic tape. DS = decade switches. TD = telephone dial.

that the system can be employed as a playback system in circumstances where this is more desirable, the memory merely accepting the signals from the transducers during manual positioning instead of the numerical information from the tape. The measuring device consists of discs geared to the leadscrew which, in the positioning form of the system, function as optical digitizing discs.

Developments in Continental Europe

Continental Europe was almost unrepresented in the previous survey and, of all countries, the most surprising omission was undoubtedly Germany, with its great machine-tool industry and record of forward thinking. It may well be that the German machine-tool builders took a cautious view of numerical control ten years ago; if so, this would be understandable as development costs were high and European industry, lacking any support on the scale of that provided by the U.S. Air Materiel Command, was conservative in its attitude to numerical control. Furthermore, the German machine-tool industry was heavily committed to programme control as a form of automatic operation; in fact, the author's survey of programme-controlled machine tools[11] shows that many programme-control systems originated in Germany.

Recently, however, there has been an increasing interest in numerical control by German machine-tool builders. Since the question of Germany's former and present attitudes to numerical control has been quite fully discussed elsewhere[12], it is now proposed to consider the positional control systems used on German machine tools.

From Table I, a feature which will be noted immediately is the fact that all German systems offering permanent storage use 5-channel punched tape. In view of Germany's late entry into the field of numerical control, it may seem surprising that 8-channel tape was not used, especially in view of the fact that the American data-processing industry had thought 8-channel tape to be so important that considerable upset was suffered in order to effect the change. The adoption of the 5-channel tape was very likely due to a combination of circumstances;

(11) R. C. BREWER. "Programme-Controlled Machine Tools". *The Engineers' Digest*, Vol. 21, No. 6, p. 77.
(12) R. C. BREWER: "German Developments in Numerical Control", *Control*, Vol. 4, No. 32, p. 91.

thus, it was the standard input tape for German computers, it had been the standard for the International Telegraph Code for many years, and most of the British and Russian control systems used 5-channel tape, even if not with the standard International Telegraph Code.

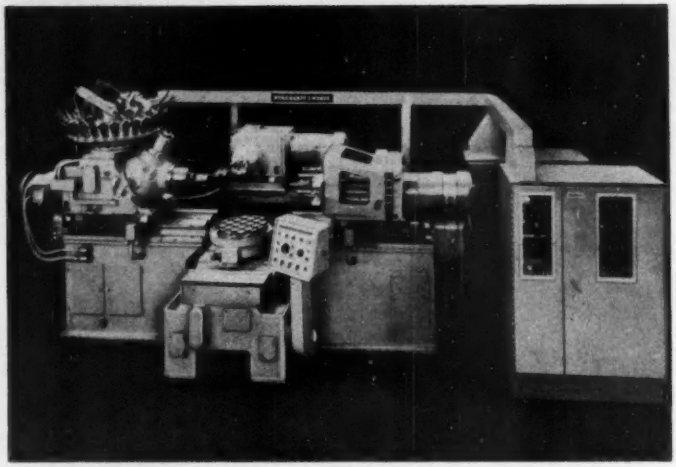


Fig. 19. The Burkhardt and Weber special tool-changing machine equipped with the Hughes Aircraft control system.
(Courtesy of Burkhardt & Weber K.G.)

A second, and rather curious, feature which shows up in Table I is the use of a positional control system on vertical milling machines. Such machines can only exploit numerical control to the fullest extent if a contouring system is used, and positional control limits them to the *modus operandi* of a programme-controlled machine. In most cases, this limited numerical control would show time savings over programme-control, but it is doubtful whether many components would show a saving in cost.

In addition to the purely German control systems listed in Table I it should be mentioned that two American systems are used on German machine tools. Of these, the Burgmaster turret drilling machine (made under licence by Karl Hüller) is controlled by a two-axis General Electric system, while the Burkhardt and Weber special-purpose machine uses the Hughes Aircraft system. Both of these systems, of course, use the standard American 8-channel tape as the transfer medium. The Burkhardt and Weber machine, illustrated in Fig. 19, is an interesting and rather complex machine, with a universal indexing turret, holding up to 30 tools at the headstock end. At what would normally be the tailstock of the machine, multi-tool heads for drilling, boring, and milling can be brought into position, as required. Foreseeing that many customers would not require such a complex machine, Burkhardt and Weber have designed the machine on a unit basis, so that, in fact, customers may purchase as much or as little of the machine as they want. The table has two rectangular co-ordinate movements and a rotary movement, the positioning accuracy being $\pm 0{\cdot}02$ mm, with a repeatability of $\pm 0{\cdot}0075$ mm.

Sweden is a country with a well-established, if not large, machine-tool industry. Like Germany, Sweden has not been greatly enthusiastic about numerical control, and the first machines to be designed for, and fitted with, control systems are the Köping vertical milling machines, which carry the Ferranti contouring system (to be described later). The Köping Company is, however, collaborating with Svenska Aeroplan A.B. (SAAB) to produce an all-Swedish numerically controlled machine tool. As might be expected from a small country which balances its economy by exporting hardware, flexibility is the keynote of the SAAB system. Thus, the input can be on either 5- or 8-channel tape, and metric and inch versions can be purchased. Furthermore, there is provision for controlling up to three rectilinear movements and one rotary movement.

A block diagram of the SAAB system is shown in Fig. 20. The tape is read in an electro-mechanical reader, a parity check being used to detect errors in punching and/or reading. The system permits functional and numerical commands, the latter being contained in a block of four lines indicating the direction of movement, spindle speed, feed rate, and the measurement unit, which may be the decimetre, centimetre, millimetre, or 0·1 mm in the metric system, and 10, 1, 0·1, or 0·01 in. in the inch version. The measurement unit is of importance, since the whole system is based on a unit-displacement principle. It should be noted that the first line of each block on the tape refers only to the direction of movement and not to the amount of movement. In fact, as soon as the first line is read, the table begins to

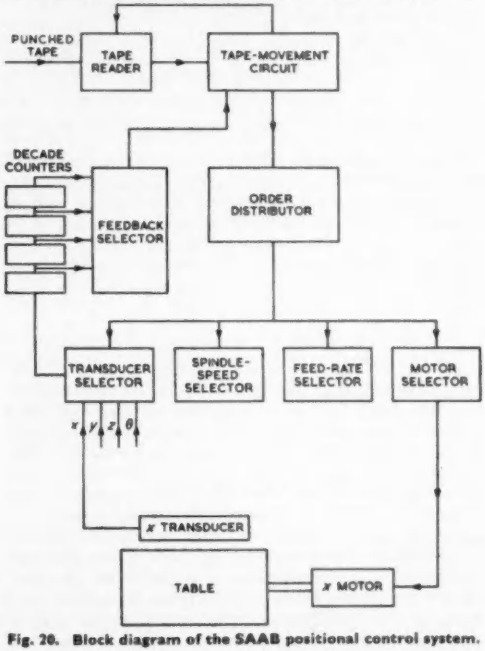


Fig. 20. Block diagram of the SAAB positional control system.

move in the specified direction. The transducer (an optical digitizer) then feeds back to the tape reader one pulse for every measurement unit travelled and, as each pulse is received, the tape is stepped forward one line. This procedure continues until a point is reached where the tape contains a stop code or the information for the next point. The tape reader therefore also functions as the comparator.

Reference to Fig. 20 shows that an order distributor is used to route the information from the four-line block on the tape to the selectors for the transducer, spindle speed, etc. The feedback pulses from a given transducer are fed back via the transducer selector to decade counters which, consistent with the measurement unit specified, feed pulses at the required rate to the feedback selector and thence to the tape-movement circuit. The tape reader and recording circuitry impose a limiting positioning speed of 13 units per second (expressed in whichever measurement unit has been chosen). As with many other systems, a mirroring technique can be used for producing left-hand parts from right-hand tapes, and *vice-versa*.

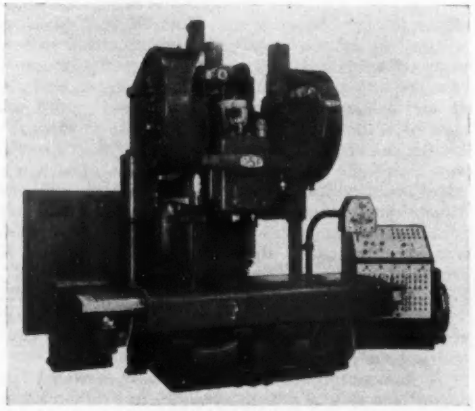


Fig. 21. General view of the "G.S.P.-matic" automatic tool-changing machine.
(Courtesy of Ateliers G.S.P.)

Surprisingly little attention has been devoted to numerical control in France and, even now, there appear to be only two systems developed by commercial undertakings (counting Renault as a commercial concern). There has been some information, however, about an invention patented by the Centre de Recherches Scientifique Industrielles et Maritimes de Marseille, a department of the Centre National de la Recherche Scientifique[13]. The subject-matter of this patent is of interest as an example of how simple and how relatively devoid of electronics a control system can be. Information is permanently stored as perforations on a paper cylinder, and the transducers are revolution-counters using electrical contacts accurately spaced round the periphery of a contact drum. The whole control system is contained in a small volume, the prototype shown at the recent MESUCORA Exhibition in Paris consisting of a simple rack of shelves carrying not only the control equipment but also the transducers. This is rather unusual and demands that the leadscrews of the machine be coupled, perhaps over several feet, to the control equipment. This arrangement would undoubtedly need modification if a high-speed positioning system were required.

Berthiez have announced plans for equipping one of their vertical lathes with numerical control based on digitizing discs as transducers. This lathe, however, will not be offered for sale until the summer of 1962, so that this would appear to leave the "GSP-matic" and Renault drilling machine as the only French numerically controlled machine tools. Manufactured by Ateliers G.S.P., of Courbevoie, the "GSP-matic" consists of a co-ordinate table and a cross-slide moving vertically up and down the column. The cross-head carries a heavy-duty spindle and a light-duty, high-speed spindle. On the left-hand side of the column is a rotary tool-changing unit which can accommodate up to 18 tools and cutters for the heavy-duty spindle (Fig. 21). On the right-hand side, another rotary unit carries up to 36 tools for the high-speed spindle. The mean times for tool changing are 16 sec for the heavy-duty spindle and 9 sec for the high-speed spindle.

Punched 35-mm film or tape is used as the transfer medium, this containing the numerical information for the X, Y, and Z axes and the functional commands. All the usual tape-punching and verifying facilities are available. The operation of the control system is very similar to that of the Fosdick system (described in the previous survey), using length bars (or gauge rods) held in decagonal turrets which are indexed into their correct positions from the numerical information on the tape; the table is then driven until the bars are stacked end-to-end, at which stage the operation of a microswitch stops the table drive. The accuracy of the system is thus a combination of the tolerances of the length bars and the effectiveness of the stopping mechanism.

The Renault PCN 1 drilling machine, shown in Fig. 22, has been equipped with numerical control so as to improve its utility in machining small batches. The control system itself has been designed and developed within the Renault organization. The machine is rigidly constructed and carries a pneumatically balanced quill for the drills, etc., this quill being powered by a 4-hp motor through an 8-speed gearbox. The head itself moves up and down the column under the power of an asynchronous motor (for speeds up to 1 ips) or a d.c. motor (for speeds of

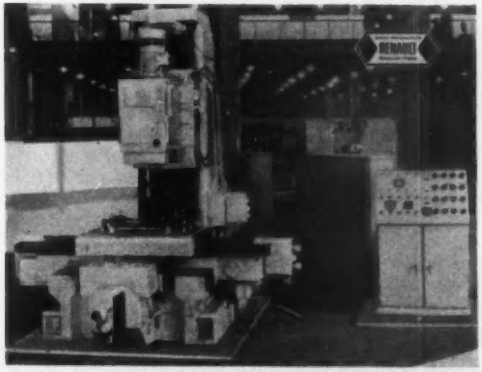


Fig. 22. The Renault PCN1 drilling machine with positional control system.
(Courtesy of Régie Nationale des Usines Renault)

(13) V. Gavreau, A. Calaora, and M. Miane: "Commande Numérique Simplifiée des Machines-Outils par le Robot IV". Notice numéro 45. Centre National de la Recherche Scientifique, Marseilles, France.

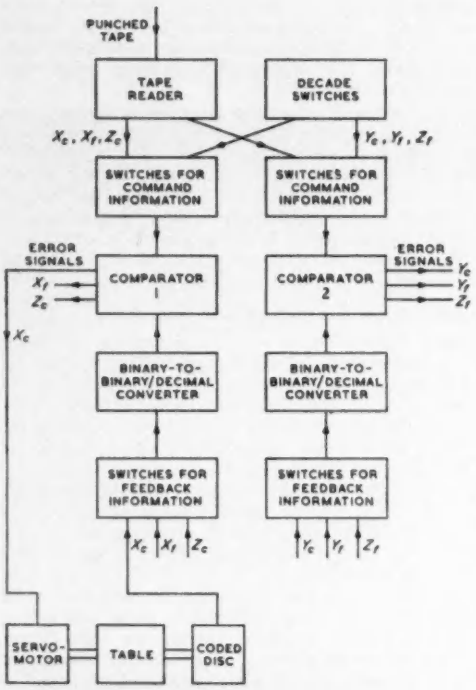


Fig. 23. Block diagram of the Renault positional control system.
Xc, Xf coarse and fine signals for *X* axis
Yc, Yf coarse and fine signals for *Y* axis
Zc, Zf coarse and fine signals for *Z* axis

0·2 to 4 ipm). Since it was not considered necessary for the table to be positioned at different speeds, asynchronous motors are used for this purpose. The table always positions from the same direction and, when the error-signal is reduced to zero, the table is pneumatically clamped.

Numerical information can be fed into the system either by decade switches or by 8-channel punched tape. The transducer, which is digital and has a resolution of 1 in 10,000, consists of two coded discs, each having a resolution of 1 in 100; one disc (the fine disc) rotates at the same speed as the leadscrew, while the other (the coarse disc) is driven at one-hundredth of the leadscrew speed. Each disc carries 8 circular tracks consisting of transparent/opaque patterns sensed by 16 photocells. The fine disc senses the millimetres and tenths of millimetres, while the coarse disc senses the decimetres and centimetres. The feedback signal, however, is in binary coding and consequently, to enable comparison to be effected with the command information, which is coded in binary-decimal form, a binary to binary-decimal converter is needed. However, in an attempt to simplify the system somewhat, Renault decided to employ only two comparators and converters, despite the fact that three axes were to be controlled; consequently, the feed-back signals from the coarse and fine transducers for the *X*, *Y*, and *Z* axes are passed through the two transducer switching networks, as shown in Fig. 23. This means that a given comparator (say, comparator No. 1) must effect comparison of the coarse *X*, fine *X*, and coarse *Z* positions sequentially, and clearly similar switching is needed to convey the command information from the tape-reader or decade switches to the command side of the comparator.

The Société d'Electronique et d'Automatisme is marketing a system of automatic control suitable for a measuring machine but not for a machine tool—at least not in the true sense of numerical control, although only minor additions would be needed to make it a machine-tool control system. The previous survey described a digital system developed by this company, but the current system is analogue, using the transducer discussed in the previous section. Coarse resolution is effected by counting the number of pitches (each 2 mm) and this is further resolved to 0·01 mm by the voltage analogue part of the transducer.

In the application of the system to a measuring machine (Fig. 24), the sine and cosine voltages from the transducer are fed to the stator windings of resolver R_1, and the rotor is oriented by the servo-motor until its voltage nulls, the rotor voltage being fed to the servo-motor through the amplifier. While nulling the rotor voltage, the servo-motor also drives the counter (coarse measurement in units of 2 mm) and the micrometer drum (one revolution = 2 mm); thus, the combined readings of the counter and drum at any instant record the position of the table. In order to establish a datum, the counter can be disengaged and can easily be set to zero, as it is ambiguous and repeats every 2 mm. The micrometer drum position, however, is associated with one definite sine-cosine voltage pattern and, to permit adjustment of the drum without throwing it out of phase with the transducer, the differential resolver R_2 is introduced between the sensing head and the resolver R_1. For application to a machine tool, various simple modifications could be made if the command information were entered by decade switches, but some more convenient form of data-handling is really required.

A numerical control system, largely intended for stepped and tapered components, has been developed in Belgium by ACEC on the initiative of the Institut pour

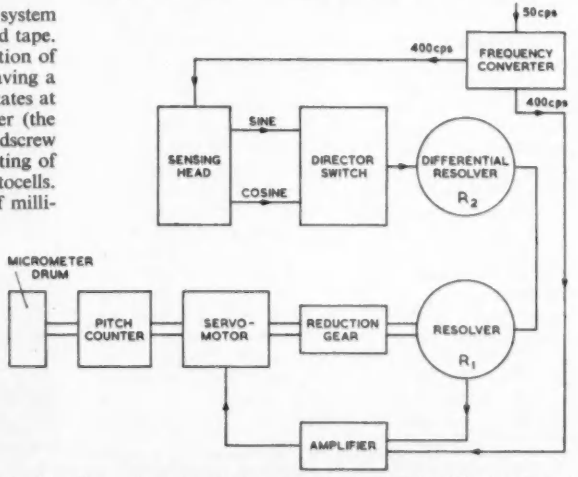


Fig. 24. The positional control system of the Société d'Electronique et d'Automatisme as applied to a measuring machine

l'Encouragement de la Recherche Scientifique dans l'Industrie et l'Agriculture (IRSIA). Control is effected on the position of the saddle along the *X*-axis (feed) and *Y*-axis (cross-feed), selection of spindle speed, and the axial position of the tailstock. A positional accuracy of 10 microns is claimed, the carriage being monitored either by a speed-control servo loop or by a position-control servo loop, but not both. The speed-control loop operates most of the time, the positional loop coming into operation when the carriage is about 1 mm from the final position. In view of this, it was not felt possible to turn taper work to finish-turning accuracy without the addition of several control loops and, as an alternative, it was decided to control numerically a taper-turning attachment to $\pm$ 1 minute of arc on the cone angle.

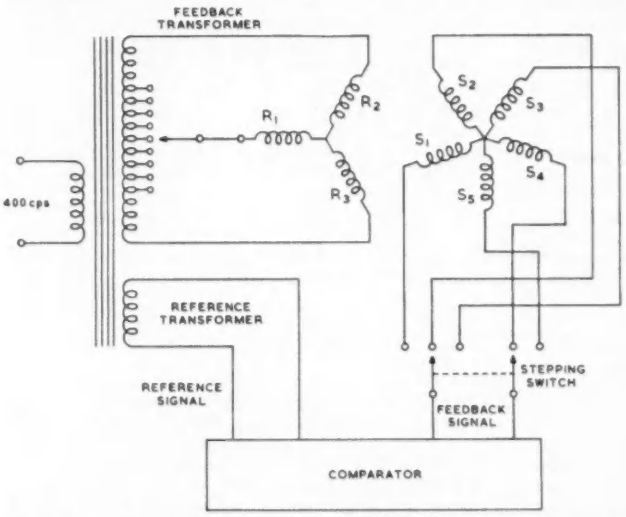


Fig. 25. The special synchro used in the ACEC positional control system.

Digital counting circuits are used for coarse resolution (integral numbers of millimetres), and the fine transducer is a special synchro (Fig. 25) consisting of a 3-pole rotor and a 5-pole stator. Of the five windings on the stator, only two are used simultaneously and these are never adjacent windings. One revolution of the rotor corresponds to a 2-mm displacement, so that, to obtain a resolution of 0·01 mm, a subdivision of 1 in 200 must be effected. To achieve this, suppose for the moment that the rotor winding R_1 is connected to the mid-point of the feedback transformer. Then, if the five windings of the stator are taken in pairs (but never adjacent pairs), ten combinations are obtainable, each pair having some position at which zero voltage is induced. These ten positions are at 0·2-mm intervals, constituting the primary fine resolution. The remaining division of 0·2 mm into twenty 0·01 mm intervals is effected by connecting the rotor winding R_1 to points slightly removed from the mid-point of the secondary winding of the feedback transformer; naturally, these points have to be very carefully adjusted. The output variations from the synchro are compared with the signal from the reference winding. The storage medium is 32-channel punched tape, and the channels can carry either numerical (positions in units of 0·01 mm) or functional commands.

Switzerland, with a well developed electronics industry, has probably not entered the numerical control field before, because most of its machine-tool industry is concerned with the special-purpose machines in which it excels. Recently, however, at least four systems have become available. Of these, Erni, of Zurich, has developed a positioning system which, although not specifically linked to one machine-tool manufacturer, has been applied to a Menziken vertical lathe. The input is on special wide punched tape, having 80 channels, the numerical information being in units of 0·01 mm. Photoelectrically-sensed digitizing discs are used for displacement measurement, each pulse representing a movement of 0·01 mm. Comparison of the command and feedback pulses is effected in the manner normal for a pulse-counting system, as described in the previous survey with regard to the Ferranti system.

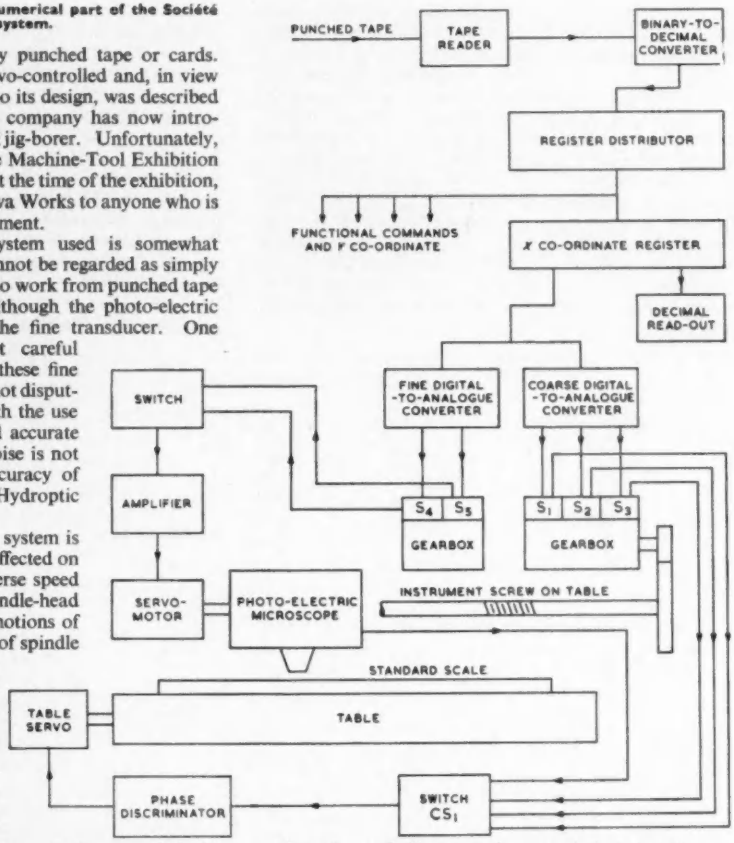
The Fritz Werner milling-machine with Brown Boveri positional control was first shown at last year's Hanover Exhibition, but it was clearly a prototype model since it carried only one servo-motor, and positioning along the axes had to be accomplished sequentially and not simultaneously. The company has, however, made it clear that all production models will carry one servo-motor per axis. The Brown Boveri system employs as the transducer an optical digitizer geared to a precision rack integral with the machine table, the resolution being 0·01 mm. The operating torque for the digitizer is extremely low, so that wear is quite small, and backlash has been minimized by making the pinion in two halves and springing them against each other.

Most numerical control systems employing correction for the errors of leadscrews or racks effect the correction mechanically, whereas the Brown Boveri system corrects errors electro-mechanically. An error curve is determined for the rack and, at points where the error exceeds the specified limit, a small cam is placed alongside the rack. During table movement, these cams operate one of a pair of micro-switches on the table (for positive and negative errors) to trigger a circuit which injects a positive or negative pulse into the pulse train fed back from the digitizer to the comparator. In other respects, this system is similar to other systems based on pulse-counting techniques.

The Contraves system is more specifically associated with the Oerlikon Machine Tool Company, to one of whose drilling-machines it has been applied. The input information on 5-channel tape is read and passed into a relay buffer store. When required, the command information is taken from the buffer store and converted to analogue form in a digital-to-analogue converter. The feedback signal from the differential capacitor is compared with the analogue form of the command information in a phase-sensitive bridge, and the error signal is used to monitor a d.c. motor.

The fourth Swiss company is the Société Genevoise d'Instruments de Physique. Their large "Hydroptic" jig-borers have been available for about two years with a playback system of control, numerical input comprising operations carried out by a human operator to produce

Fig. 26. Block diagram of the numerical part of the Société Genevoise system.



the first piece, rather than by punched tape or cards. The system was, however, servo-controlled and, in view of the care which had gone into its design, was described in the previous survey. This company has now introduced a numerically controlled jig-borer. Unfortunately, this will not be on show at the Machine-Tool Exhibition in Brussels, but will be ready, at the time of the exhibition, for demonstration in the Geneva Works to anyone who is interested in this new development.

The numerical control system used is somewhat different in conception and cannot be regarded as simply the playback system modified to work from punched tape instead of memory drums, although the photo-electric microscope is still used as the fine transducer. One point which should prompt careful reflection is that, even with these fine machines, whose excellence is not disputed the world over, coupled with the use of an extremely sensitive and accurate transducer, the Société Genevoise is not prepared to guarantee an accuracy of more than 0·00015 in. on the Hydroptic 6A, or 0·0002 in. on the 7A.

A block diagram of this system is shown in Fig. 26. Control is effected on both the positioning and traverse speed of the table (*X*) and of the spindle-head saddle (*Y*), on the vertical motions of the quill, and on the selection of spindle speed and feed. The positions of the table and spindle-head saddle are, for convenience, also displayed on a decimal read-out. The heart of the system is the photo-electric microscope described in the previous survey, which has been used for automatically controlling dividing engines on which are ruled the length standards which the company engraves for national standardizing authorities throughout the world. In the numerical control application, the photo-electric microscope observes the standard scales on the jig-borer, but, with the relatively small expense of providing conventional microscopes, the machine is still capable of human operation when numerical control is economically or technically undesirable.

The vertical motion of the quill is not numerically controlled by the punched tape but by a magnetic memory which can provide numerical information in accordance with certain standard cycles of quill movement. This numerical information is derived from settings by the operator when the first component is produced, buttons marked "Surface" and "Depth" being depressed when the tool first contacts the surface of the work and again at full depth of penetration. Position measurement of the quill is effected by three synchros, i.e., coarse, medium, and fine. For the "Surface" position, a high degree of accuracy is not required, and only the signals from the coarse and medium synchros are recorded. This procedure may appear to be rather wasteful of time, but it should be borne in mind that, if quill-movement were tape-controlled, the operator would have to effect fairly accurate adjustment of tool position, whereas, in the proposed system, tool adjustment is unimportant within wide limits. The company considered the question of setting the tool diameters but concluded that it was impossible to design any automatic device of sufficient accuracy at a reasonable cost.

Any engineer with a good knowledge of machine tools in industry will be aware of the number of jig-borers produced by this company which are from 30 to 40 years old and which are still in operation. Coming to more recent times, most of the jig-borers delivered just before the war are still working well after anything from 50,000 to 100,000 hours of use. Consequently, the reliability and life of electronic equipment was of some concern to the company, and it was decided to use the best components available, even if some were expensive, e.g., tantalum condensers. Naturally, transistors were used wherever possible.

The input information is on 8-channel tape to the standard code shown in Fig. 1. An addressed code is used, i.e., each group of numbers representing a co-ordinate is preceded by a letter which ensures that this piece of information is routed to the correct part of the control system. This means that the order in which co-ordinates and functional commands are given is immaterial and that items which are common to two adjacent blocks of information need not be duplicated—a big advantage on a jig-borer. The binary-coded information on the tape is read by a standard Friden or Creed reader and passed through a binary-to-decimal converter to a distributor, which routes the relevant

items of information to the registers for the co-ordinates and functional commands, i.e., tool selection, quill movement, etc., as shown in Fig. 26. These registers act as buffer stores for holding the information in digital (decade) form and also display the information on decimal read-outs (as co-ordinates, tool numbers, etc.).

With regard to the numerical commands, consider one co-ordinate, say the X co-ordinate. The information from the register is converted to analogue form (voltage), using two converters, one for coarse positioning and the other for fine positioning. The coarse voltage energizes the stator windings of the coarse synchros S_1, S_2, and S_3, which are geared to one another and, via an instrument screw, to the table. The coarse-error signal is the output from the rotors of the synchros, control being passed gradually from the coarsest to the finest. The coarsest synchro (S_1) rotates through half a revolution for the complete table travel, so that the direction of movement is easily discriminated, while synchro S_3 controls table movement to hundredths of an inch. At this stage, the table is near enough to its final position to enable the photo-electric microscope (already accurately positioned by synchros S_4 and S_5) to pick up the relevant line on the standard scale. Switch CS_1, which electronically passes control from S_1 to S_2 to S_3, now switches in the output from the photo-electric microscope, i.e., the fine-error signal. The output from switch CS_1 is either the coarse- or fine-error signal which controls positioning of the table by the servo-motor. The phase discriminator merely controls the direction of displacement.

Pneumatic Control Systems

During the first decade of numerical control, electronics undoubtedly reigned supreme but, with the recent advances in pneumatic bi-stable state devices (leading to the possibility of pneumatic digital computers), there has been an increasing urge to design a non-electronic machine-tool control system. So far, there appears to be only one such system, i.e., that developed by Moog Servocontrols Inc. and described by Brown[14]. The input information is binary-coded on standard 8-channel punched tape and read by a pneumatic tape-reader, which converts the numerical information into air pressures. These pressures control two multi-level binary valves, one for coarse and the other for fine positioning by hydraulic means. The valves consist of a series of tiers with ports arranged according to a binary pattern, as shown in Fig. 27a. For clarity, the coarse binary valve is omitted in Fig. 27b. Coarse positioning is in inches and tenths of inches, and the ports at the top of Fig. 27b are spaced at 0·1-in. intervals. The whole concept of the system is based on one simple fact, i.e., that if one of the ports is opened to the sump (by the binary valve), then the hydraulic piston of the linear controller is subject to unbalanced forces which are only equalized when the piston is opposite the port in question. Consequently, coarse positioning is a matter of opening the correct port to the sump.

Fine positioning is achieved in a manner similar in principle to that used in the Canadian Westinghouse electromagnetic transducer (described in the previous survey). It will be noted that the piston is not perpendicular to the linear-controller axis but is inclined, as in a swashplate motor. Accordingly, if the linear controller is rotated, it is also forced to move linearly because the piston is in equilibrium only when it is symmetrically placed about the port which is open to the sump. Since either half of the piston periphery is a helix of 0·2-in. lead, the amount of linear movement is naturally proportional to the angle of rotation, a half-revolution causing a linear movement of 0·1 in. Rotation is derived from the rotary interpolator (Fig. 27a), which seeks the port opened to the sump in the same way as the linear controller. The problem of fine positioning is thus one of opening the correct port to the sump, according to the information regarding the hundredths and thousandths of an inch.

The linear controller cannot position the table directly, because it is, in effect, a transducer operating at a low power level. It can, however, sense the table position (as shown) and can control a normal 4-way servo-valve which monitors the table power source (a hydraulic ram). An accuracy of $\pm 0{\cdot}0005$ in. is claimed for this system.

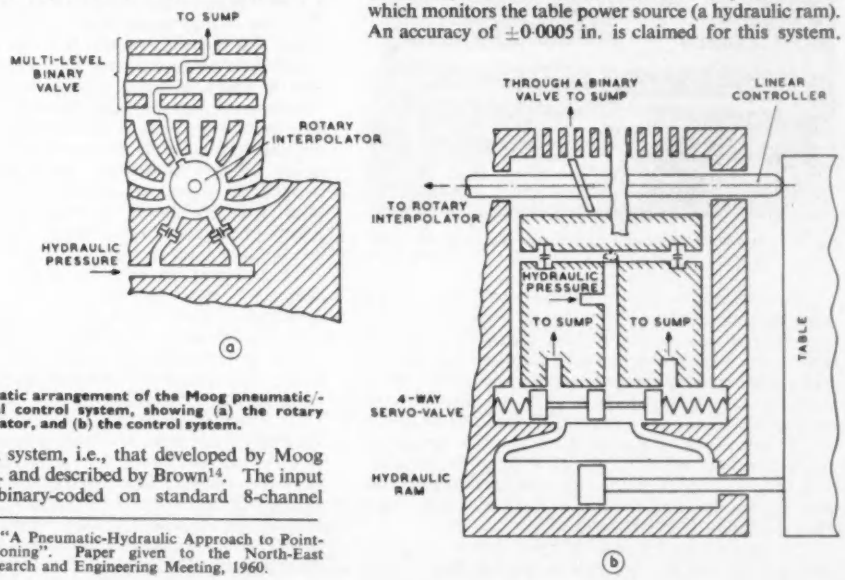


Fig. 27. Diagrammatic arrangement of the Moog pneumatic/-hydraulic positional control system, showing (a) the rotary interpolator, and (b) the control system.

(14) E. C. Brown: "A Pneumatic-Hydraulic Approach to Point-to-Point Positioning". Paper given to the North-East Electronics Research and Engineering Meeting, 1960.

CONTINUOUS CONTOUR CONTROL SYSTEMS

Recent British Developments

In the previous survey, the continuous contouring system of A.E.I. (Rugby) Ltd. (formerly B.T.H. Ltd.) was briefly described but, since more can now be said about it, it is felt apposite to treat this system again in the present survey. The system can effect three-dimensional control and has been applied to the Newall "Contimatic 1520" precision milling and boring machine, the preparations for machining a given component falling into the two usual stages of programming and computation.

In the A.E.I. system, known as the "Numeritrol", programming does not differ materially from any other system using a director. Straight lines and circular arcs need be specified only by the co-ordinates of their end-points and the radius of curvature (infinite for straight sections). With regard to numerical information, the planning engineer has merely to determine the sequence in which the contours are to be machined and to prepare a table of the co-ordinates of end-points and radii of curvature. The offset of the cutter centre is allowed for in the automatic computation of the cutter path. A facility for cutter-radius correction is provided, so that roughing and finishing cuts can be made from the same tape. The provision of cutter-radius compensation in digital data-processing systems has always been controversial (the previous survey pointed out the costs and complexity of logical circuitry), but the A.E.I. computer engineers have apparently come down on the side of providing such a facility.

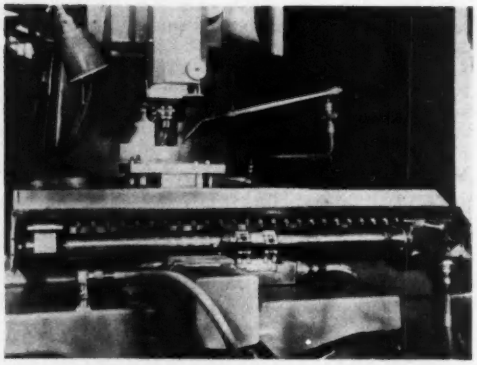


Fig. 28. The A.E.I. helixyn mounted in a machine-tool table. *(Courtesy of A.E.I. (Rugby) Ltd.*

Roughing and finishing from the same input data are made even more practical by the fact that the machine-tool tape can be run at half-speed, thus halving all feed rates. The only feed rate which the planning engineer need specify is the maximum, but an assessment of servo performance is required for a given machine, so that maximum acceleration and deceleration can be estimated (A.E.I. call this a "figure of merit"). The director is programmed to associate feed rate with radius of curvature, and thus automatically effects the decelerations and accelerations which will be necessary to maintain accuracy when the radius of curvature is small.

The director is a special-purpose digital computer which accepts the punched tape containing the planning engineer's information. The best computing accuracy is $\pm 0{\cdot}0001$ in., corresponding to a feed rate of 45 ipm and a cutter-radius compensation range of $\pm 0{\cdot}038$ in., but coarser computing accuracies of 0·0002 in. and 0·0005 in. are available at correspondingly higher feed rates. The computer is obviously an expensive item and A.E.I. therefore maintain a computer centre at Leicester as a service to customers.

The transducer is normally the A.E.I. helixyn (described in the previous survey), shown mounted on a machine-tool table in Fig. 28. Where less accurate position-measurement is satisfactory, synchros driven from a precision rack can be used.

The A.E.I. system has solved the problem of resynchronization within quite wide limits by the provision of a synchronizing zone, within which the machine tool will realign itself if, for any reason, there is a break in the transmission of information. The width of this zone is $2^{10} = 1024$ times the computer accuracy, so that, for the finest computing accuracy of 0·0001 in., the machine tool will realign itself with the command position, provided that the table can be positioned in such a way that the error does not exceed 0·0512 in., or half the synchronizing zone.

Until recently, there were two basic E.M.I. contouring systems, i.e., the 3D skin-mill system, which is sold in the U.S.A. as the Cincinnati control system, and a model for the European market, which was mainly a 2D or 2½D system. The company has now introduced a new system capable of effecting the normal E.M.I. parabolic interpolation in all three principal planes. There have been changes outside the analogue unit, such as the use of E.I.A.-coded 8-channel tape as the input, and cutter-radius compensation up to 0·5 in., instead of 0·15 in., but the most interesting change is in the analogue interpolating stage.

Recapitulating briefly from the previous survey, the E.M.I. system takes points along the curve to be machined in triplets, the mid-point being called a minor point, and the other two being called major points. A parabolic arc is interpolated through these three points, and its length is called a span, which is divided into 26 sub-spans, each sub-span being interpolated linearly into 64 intervals. Thus, each basic unit of the curve is divided into $26 \times 64 = 1664$ intervals, all equal in length. If it is recalled that variations in feed rate are achieved by programming major points at smaller or larger intervals, it will be seen that there is a discontinuity in feed rate at any major point which separates two spans of unequal length. Inertia in the system as a whole prevents the infinite acceleration which this demands from being achieved, but it would obviously be desirable to effect a more gradual transition. This has been effected in the new system by gradually altering the lengths of the finest intervals on each side of a change point which separates unequal spans, as illustrated schematically in Fig. 29.

It should be pointed out that, in the actual system, transition is accomplished over about twenty points each side of the major point. Electronically, this is achieved in such a way that, as a major point is approached, the next span is scanned and the voltage corresponding to its smallest interval is determined. An increasing proportion of this voltage is gradually mixed with the voltage for the current span. Although this may appear, on paper, to be

very complicated, it is, in practice, achieved fairly easily with the aid of a few tapped transformers and minor modifications in the wiring of the circuitry.

There has been no basic change in the control unit of the Ferranti curve-generating system, but there has been a certain amount of re-thinking about the data-processing stage. From the inception of their Machine-Tool Control Division, it has been a cardinal and unchanging policy of Ferranti that as much of the data-processing as possible should be effected electronically. In the early days of the development of numerical control, few computers were commercially available, and Ferranti developed the special-purpose computer described in the previous survey. The cost of such a computer was naturally high and, in view of its special nature, it was suitable only for a computer centre.

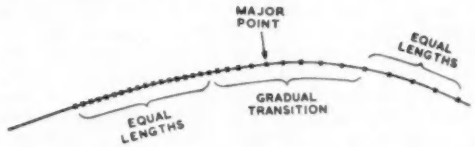


Fig. 29. Gradual change in interval length from one span to the next in the E.M.I. continuous contour control system.

Now that there is a fairly wide choice in general-purpose computers, Ferranti have decided that the special-purpose computer would be more profitably replaced by a general-purpose computer plus a digital differential analyser. The digital differential analyser for machine-tool control is a special-purpose item and its function is to make basic curve calculations, i.e., to work from the differential equations of the curves in their finite difference forms. This analyser has been designed to handle straight lines and circular or parabolic arcs, as it was felt that the ellipse and hyperbola facilities offered previously were of negligible engineering application. Other curves are handled in such a way that the curve, described by a series of points lying on it, is fed to the computer, which selects the points sequentially in quadruplets, calculates the constants in the finite difference equations and feeds them to the digital differential analyser, which accepts these constants in the same way as it would accept the constants for one of the mathematically defined curves.

The analyser works 26 times as fast as the machine tool, i.e., one hour of analyser time will keep the machine tool working for 26 hours. This ratio is virtually constant, but that for computer time to machining time varies with the computer; thus, the "Pegasus" computer will work from about 8 to 16 times as fast as the machine tool, and the "Orion" computer 50 times as fast. With these variable ratios, it is clear that one element could easily hold up the other and, in order to prevent this, paper tape is used as the link between elements.

One interesting new feature of the Ferranti error-checking system is its ability to correct for defective pulses. A check is made at the computer to ensure the detection of any places where two or more consecutive pulses are missing. At the control unit, one or two pulses can be injected in places where they are missing, so that there should be complete protection against defective pulses. In addition to the applications mentioned in the previous surveys, the Ferranti system is being used to control VF10 vertical milling machines built by Köpings Mekaniska Verkstads AB for the Swedish telephone company, L. M. Ericsson. These machines will use re-circulating ball nuts and will carry full three-dimensional control.

The Research Department of the Staveley Group has developed a continuous contour control system which is intended to be applied to Archdale milling machines. Fig. 30 is a block diagram of this system for the X-axis. The input information is on 5-channel punched tape and is fed to a digital differential analyser, which calculates co-ordinates at 0·0001-in. intervals. The analyser is a special feature of this system, being very compact and likely to sell at such a price that customers purchasing the control system will give at least serious consideration to buying it, although it is intended to offer a data-processing service. The limitation of the analyser is that it can process data for straight lines and circular arcs only, although it would not be over-difficult to include hyperbolas and parabolas. However, an easier way of dealing with curves other than circular arcs is to use the analyser in conjunction with a general-purpose computer, and this possibility is being investigated with regard to the Elliott 803 computer.

In a continuous contour system, the most convenient way of using the Staveley transducer previously described is to measure the phase change of the rising edge of the square wave, which is the output from the transducer. Consequently, a digital-to-analogue (phase) converter is included in the data-processing stage, and the machine control information is recorded on 4-channel magnetic tape in analogue form. Channel 1 contains a signal for the switching frequency (say, the reference signal), and channels 2, 3, and 4 contain the X, Y, and Z numerical

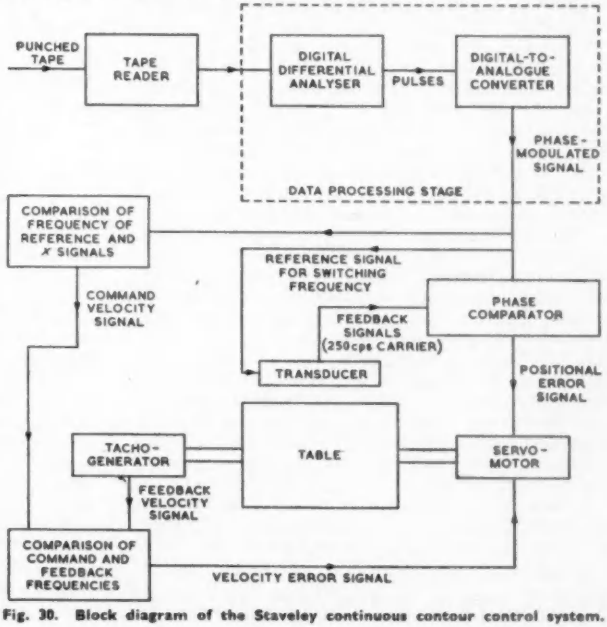


Fig. 30. Block diagram of the Staveley continuous contour control system.

information in phase form, the square wave being advanced 360 deg. for every 100 pulses, i.e., the pitch of grating lines or 0·01 in.

In the square waves for the *X*, *Y*, and *Z* channels, the falling edge is not equally spaced with respect to the adjacent rising edges and, since only the rising edge is used for the phase comparison, the falling edge can be deliberately displaced to effect functional commands. The error signal is produced by a phase comparator which is fed from the transducer and the magnetic tape, this error signal driving the servo-motor (a d.c. motor), thus completing the positional feedback loop. As a safety measure, the whole system shuts down if the phase error exceeds a predetermined value.

There is also a velocity feedback loop to control feed rate, although this is obviously not as critical, with regard to accuracy, as the positional loop. The command velocity signal is produced by comparing the frequencies of the reference and *X*-axis signals, while the feedback velocity signal is derived from a tacho-generator on the leadscrew. These frequencies are compared to produce a velocity error signal.

Developments in the U.S.A.

Since publication of the previous survey, several new American companies have entered the field of continuous contour control, and most of the older-established companies have revised or completely changed their systems. Table II includes these new developments.

As mentioned in the previous section on positional control, the system employed by Warner and Swasey for their turret lathe may also be used as a continuous contour control system. This system is designed as a linear interpolating system, and a programme exists for the IBM 650 general-purpose computer, although there is no reason why any general-purpose computer should not be used. The input to the computer is standard punched tape, and the output is magnetic tape which carries positional information as pulses.

The digitizing discs, mentioned under positional control, are now used as pulse generators, so that both command and actual positional information are in pulse form. An electronic counter serves as a comparator, the unbalanced number of pulses being the error signal. This signal passes through a digital-to-analogue converter, so that the output can be in a form suitable for actuating the servo-motor. A very complete description of this system has been given by Mergler[15].

The Gisholt Company has used two systems developed by Westinghouse and by Specialities Inc. for their "Fastermatic" lathes, but has recently designed a new lathe for numerical control, using its own "Factrol" system. The input is 7-channel magnetic tape. The transducer is a magnetic measuring bar, as already described, and the tape-reader uses a similar screw scanning device for reading the numerical information in the four channels which correspond to the four controlled axes. Obviously, special tape-recording equipment is also required. The comparator is a discriminator which compares the phase of the command and feedback voltages.

Although the comparison is analogue, the system is not absolute and carries a built-in provision for breaking the servo-loop if the phase exceeds a specified critical value. Data-processing is by a special-purpose analogue computer. Indicative of a possible new trend is the absence of a control cabinet, as opportunity has been taken of the development from its inception to build in all the control equipment at the headstock end.

Another recent entrant to the numerical control field is Thompson Ramo-Wooldridge, Inc., a partnership between the Thompson Grinder Company and the Ramo-Wooldridge organization, who have produced a numerically controlled planer-type grinder (known as the TF 5C tape forming machine).

The longitudinal movement of the table and the elevation and cross-feed of the head can be controlled, and the machine is driven hydraulically. The input to the system is punched tape carrying the numerical information in binary-coded decimal form. The information read from the tape is converted to simple decimal form and is put into a buffer store, as shown in the block diagram in Fig. 31. The director, a general-purpose digital computer, withdraws information from the buffer store, as required, and effects a linear interpolation, converting the numerical information into the form of pulses whose density (with respect to time) is proportional to the specified feed rate. As with most contouring systems, however, the operator can override the feed rate on the tape, if required.

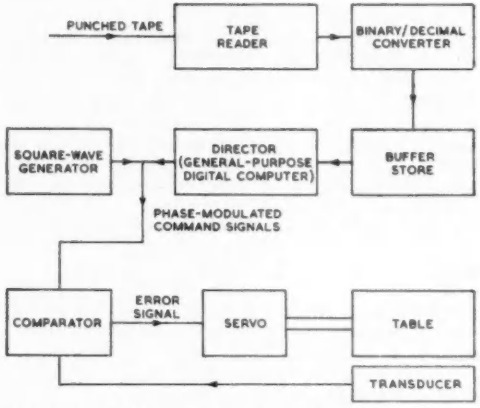


Fig. 31. Block diagram of the Ramo-Wooldridge contouring system.

The transducers are resolvers driven by precision racks or leadscrews, and consequently their feedback information is in analogue form. In order to compare the command and feedback information, a conversion must be made. In the Ramo-Wooldridge system, the director output is converted from digital to analogue form. To effect this conversion, the output from the director is used to phase-modulate a 200-cps square wave.

The chief modification to the Bendix continuous contour control system is, like the Ferranti change, the use of a digital differential analyser in the data-processing stage. The Bendix system, however, remains an interpolating system, but with the added facility of effecting circular-arc interpolation. This means that a given circular arc can be processed as one single command instead of a multitude of commands, each corresponding to a short linear segment, considerably relaxing the demands made on the reader when machining circular profiles at high feeds.

(15) H. W. Mergler: "Numerical Building Blocks Control Turret Lathe". *Control Engineering*, Vol. 7, July 1960, p. 69.

This system, known as the "Dynapath" system, has been applied to the Pratt and Whitney "Numeric" Keller—a three-axis horizontal milling machine. One interesting experiment with this machine and control system has been the machining of templates to a very high accuracy. In this experiment, no particular care was taken over the actual machining, but the template was subsequently inspected in a Pratt and Whitney numerically controlled measuring machine in order to determine the errors at selected x and y co-ordinates. These errors were then fed to a general-purpose computer programmed to effect curve-fitting on a least-squares criterion, which was rather more difficult than may be appreciated at first sight, since the apparent axes of the template are invariably subject to errors themselves. This means that the computer has to effect a best-fit curve and also to determine the axes corresponding to it. The output from the computer is thus not only the x and y components of the error at points along the curve, but also the angle between the apparent axes (used in measuring the errors) and the axes corresponding to the best curve. The template was then shaved in accordance with the output data from the computer. It is claimed that a five-fold improvement in accuracy is obtained by the use of this technique.

Developments in Continental Europe

There appears to be only one continuous contour control system originating in Continental Europe, i.e., that of the Allgemeine Elektrizitäts-Gesellschaft (A.E.G.). There is, however, a German Droop and Rein milling machine which is equipped with an E.M.I. 2½-D system (described in the previous survey). The A.E.G. system uses the five-channel punched tape input which might be expected after the remarks made in the previous section on Continental positioning systems. The International Telegraph Code is used, and co-ordinates are expressed in units of 0·01 mm.

After tape-reading, the co-ordinates are converted from decimal to binary form and are then passed to a general-purpose digital computer, as shown in the block diagram in Fig. 32), where linear interpolation is effected. The computer has sufficient sub-routines to enable the programmer to specify straight lines and circular arcs with the barest information. After interpolation, the data are converted to analogue form by a system of tapped transformers. This is reminiscent of the E.M.I. system but, in the latter, digital-to-analogue conversion is effected as soon as the tape is read, and analogue interpolation is used. Thus, the E.M.I. system is completely analogue in the post-tape-reading stage, whereas, in the

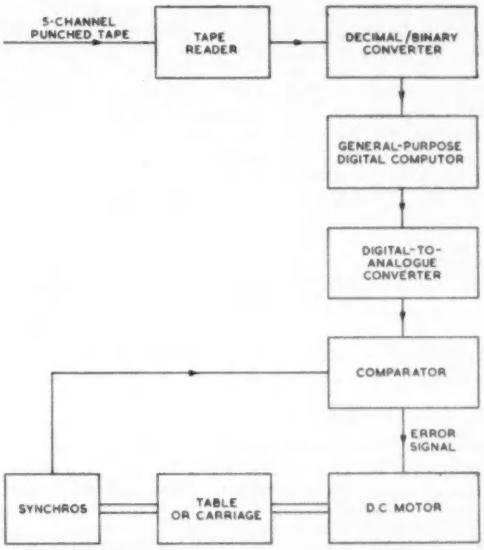


Fig. 32. Block diagram of the A.E.G. contouring system.

TABLE II: SUMMARY OF RECENT CONTINUOUS CONTOUR CONTROL SYSTEMS

Manufacturer	Typical Application	Number of Axes	Input	Transducer	Interpolation		Drive
					Type	Medium	
A.E.G., Germany	Roll-turning lathe	2	5-ch PT	Synchros	Linear	g.p. DC	d.c. motor
A.E.I., England	Milling and boring machine	3	5-ch PT	Helixyn	Linear	s.p. DC	electric or hydraulic
Bendix, U.S.A.	Horizontal milling machine	3	8-ch PT	Special 2-phase synchros	Linear or circular	s.p. DC and DDA	d.c. motor
E.M.I., England	Vertical milling machine	3	8-ch PT	Synchros	Parabolic	s.p. AC	electric or hydraulic
Ferranti, England	Vertical milling machine	3	5-ch PT	Diffraction gratings	*	*	hydraulic rams
Gisholt, U.S.A.	Turret lathe	4	7-ch MT	Magnetic measuring bar	Linear	s.p. AC	hydraulic rams
Thompson Ramo-Wooldridge, U.S.A.	Planer-type grinder	2 or 3	8-ch PT	Synchros	Linear	g.p. DC	hydraulic rams
Staveley, England	Vertical milling machine	3	5-ch PT	Optical gratings	Linear	DDA	d.c. motor
Warner & Swasey, U.S.A.	Turret lathe	4	8-ch PT	Coded disc used as a pulse generator	Linear	IBM 650 g.p. DC	d.c. motors

* Not an interpolating system, but a curve-generating system, using a g.p. DC and DDA.
ch = channel. g.p. = general-purpose. s.p. = special-purpose. AC = analogue computer. DC = digital computer. DDA = digital differential analyser. MT = magnetic tape. PT = punched tape.

A.E.G. system, the control stage is analogue but the data-processing stage is digital. The transducers in the A.E.G. system are synchros coupled to the leadscrew with corrector-bar compensation for leadscrew pitch errors. The comparator is a phase-sensitive bridge which compares the output of the digital-to-analogue converter with the feedback signals from the synchros.

It will be clear that much more development has taken place in the field of positional control than in continuous contour control. This is only to be expected as, among other reasons, costs for contouring systems are one order higher, the problems of the pre-machining stage need to be better understood, and the need to send manufacturing data outside the firm to a computer centre still antagonizes most companies. Also, the facility and readiness with which contour control can be applied are not so pronounced.

At the same time, however, it must be admitted that one of the greatest problems still is that of *selling* any system of numerical control.

MACHINE TOOLS AND THE PRODUCTION OF COMPONENTS

The Pre-machining Stage

One of the chief difficulties in the stages between the designer's drawing and the computer output is the simple fact that humans and computers neither use nor understand the same language; thus, the problem is essentially one of communication between man and machine, for which some common language system is required.

In the previous survey, the Automatic Programming Tool system developed by the Servomechanisms Laboratory of the Massachusetts Institute of Technology was described. It is now proposed to discuss a common language system developed by the Lockheed Aircraft Corporation for use with the "Drivmatic", a machine for automatically riveting curved aircraft panels. A panel to be riveted is clamped to two work-holding brackets which are attached to a frame mounted at each end in trunnions carried by the machine carriage. Positional control is maintained on the co-ordinate movements of the carriage and rotation of the frame about the axis of the trunnions. The functions to be performed by the riveting machine are thus clearly defined, and a vocabulary for the common language system was not difficult to construct. The vocabulary comprises 62 words in all, divided into four groups of words, i.e.,

(1) NOUNS:—
  (a) *General*, e.g., length, radius, table.
  (b) *Physical*, e.g., panel, stringer, work-level.
(2) QUALITIES:—
  (a) *Modifying verbs*, e.g., fully, only.
  (b) *Modifying nouns*, e.g., canted, left, lower.
(3) VERBS, e.g., change, rivet, rotate.
(4) PREPOSITIONS OF DIRECTION, e.g., in, off, to.

These words can be used to construct meaningful statements which may be simple (e.g., retract panel) or consist of co-ordinate phrases (e.g., bulkhead is 6 in. under panel). These statements are made by a human and it is the function of the computer to understand the statement and fill in all the details before passing the information to the machine tool in a form which it, in turn, can understand.

The machine tool can now be controlled by means of this common language, but the manner in which the machine tool must operate to accomplish a given task still has to be considered. It will be evident that the computer is now required to simulate the operation of the riveter and not merely to control it. If this problem can be resolved, then the computer may be left to solve the question of how a given task is to be accomplished.

By simulation in the previous paragraph is meant the construction of a mathematical model of what the riveter can do. In this particular application, Lockheeds set up a series of matrix transformations, describing the geometrical relationships between the various parts of the machine. In less mathematical terms, this means that all motions on the surface of the panel were related to motions about the trunnions, so that the computer effectively had to solve a set of kinematic equations. Consequently, the information about a point where a rivet is required would be converted from the language of the aeronautical engineer (e.g., distances from a fuselage station and a stringer) into an expansion of the common language. The object of the expansion is to give the computer sufficient information concerning the geometry of the system to enable it, rather than a human, to decide the movements needed to bring this desired point to its correct location for drilling and/or riveting.

The language was expanded by adding descriptive words, symbols for geometrical parameters, etc. The operator now need do no more than state his requirements in the most abbreviated form, e.g., "rivet at T_1", but the words in the statements must be arranged in an inviolate order. To take an example from Lakin [16], if five rivets are required between points T_1 and T_2, the only statement of this which would be meaningful to the computer is "rivet 5 spaces between T_1-T_5".

Lockheeds found that this requirement was most easily met by borrowing the "Panopticon" or word-wheel used by Ogden for his Basic English language. In the Lockheed application, this consisted of eight annuli rotating about a common axis, each annulus carrying all the words of the common language which were appropriate to its position in the sentence; for example, the first circle contained the names of members of the man-machine system, the third circle the eighteen verbs, and so on. Thus, any statement read sequentially from the outermost to innermost wheels must be a *potentially* meaningful statement to the computer, i.e., it must consist of words in the correct order, although, like a simple English sentence consisting of subject-verb-object, it need not make sense and it is the function of the programmer to ensure the sense of the statements.

Many companies who work in the contouring field and who use digital data-processing have found it

(16) H. LAKIN: "Common-Language System. Automatic Programming and Control in a Man-Machine System". Actes du 2e Congrès International de Cybernétique, Namur, 1960.

convenient to adapt a curve-plotting machine so that it will produce from the computer output a scale drawing of the curves generated in any given two dimensions. This procedure certainly enables gross errors to be seen by inspection, such as a semicircle which is the mirror-image of the one desired—an easily understandable mistake since both semicircles have the same end-point and centre and are differentiated only by the sign of the curvature. Errors of smaller magnitude may or may not be detectable, depending on the scale of the drawing and the accuracy with which it is executed.

Carrying this idea one stage further it may be asked whether any means can be devised whereby the computer output could produce a standard engineering drawing on some suitable display. Technologically, the answer must be "yes", since it has been accomplished by the Stromberg-Carlson Division of General Dynamics. An automatic draughting machine has been developed which operates on the output of the computer in the Automatic Programming Tool (A.P.T.) system, and is thus based on the same input as the control tape for the machine tool.

The basic element of the draughting system is a microfilm-recorder incorporating a "Charactron" tube, which has found application in computer centres as a high-speed printer. Indeed *Control Engineering*, in its February 1961 issue, suggests that the idea of automatic draughting arose from the use of the printer by the Naval Proving Grounds in Dahlgren, Va, for drawing experimental ship hulls from designs processed in a computer.

Fig. 33 is a block diagram showing the essentials of the A.P.T. system (full lines) and the automatic draughting system (dotted lines) which operates from the output of the arithmetic element. This output is on magnetic tape and consists of generalized information about the path of the cutter centre. In the A.P.T. system, computer sub-routines post-process these data to make them compatible with a particular system of machine-tool control. In the automatic draughting system, the output tape from the arithmetic element is fed to a different post-processing element which produces the tape for the Stromberg-Carlson 4020 printer. The "Charactron" tube of this printer displays the numerical information as an orthogonal projection (complete with dimensions, tolerances, etc.) and this is photographed by a 35-mm camera unit. The film can be stored for record purposes and copies can be made at any desired time. This procedure for producing a working drawing has obvious advantages when the component is to be produced by numerical control, since much of the data-processing has to be done anyway, and the drawing, being derived from the same input information, indicates any absurd errors in computation.

Although there is no doubt that the process is technically feasible, the high-speed printer is as costly as a medium-size computer (its rental in the U.S.A. is the equivalent of £2000 per month), so that it may prove to be economically justified only where it is bought (or rented) primarily as the output device for a computer laboratory (or centre) and where its use for automatic draughting is a method of ensuring better utilization.

For some time now, the cost of computer time and the problem of communicating with the computer have spurred many organizations into thinking of ways of eliminating ("replacing" is perhaps a better word) the data-processing stage. Most of the ideas have centred around either the supposition that a master or prototype component is available or the possibility of producing the tape from line drawings.

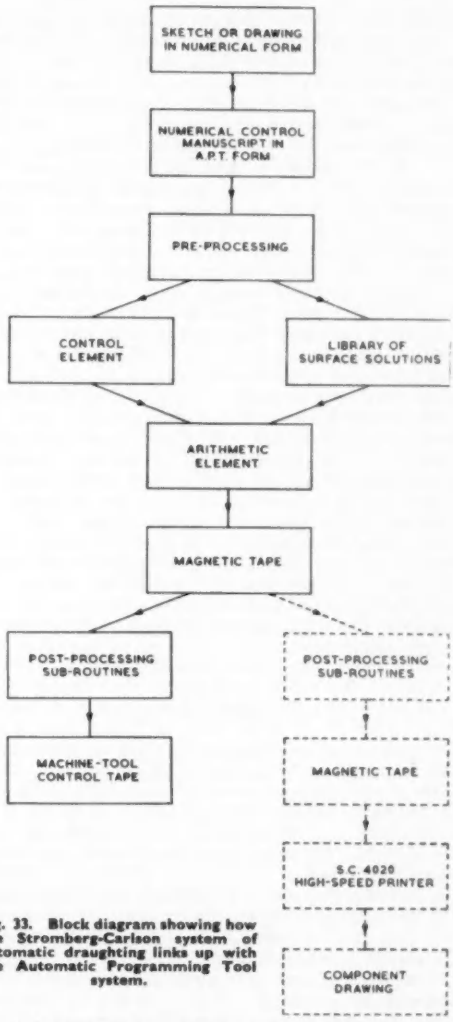


Fig. 33. Block diagram showing how the Stromberg-Carlson system of automatic draughting links up with the Automatic Programming Tool system.

With regard to continuous contour control, the question hinges greatly on how accurately the drawing can be produced (bearing in mind that scaling up or down can be employed) and how accurately the lines on the drawing can be tracked. The former problem has never been over-formidable and, now that photo-electric tracking devices have been made much more accurate and reliable, there seems little doubt that "data-processing" of this kind will soon be feasible for a wide range of components. It should, however, be regarded as complementary and not competitive to digital data-processing.

Positional control has been successfully applied to the drilling of printed-circuit boards and, since in this application, a master or prototype board is usually available, there have been attempts to eliminate the calculational part of the programming. One of these methods employed some simple measuring machine, such as a toolmaker's microscope, to determine the

co-ordinates of the holes. However, the two disadvantages of this method (the necessity to punch a tape and possible misreading of the micrometer drums) have been overcome in a rather novel way by Micro-path Inc., who originated the Topp system of continuous contour control described in the previous survey, and who have now applied the Micro-path positioning system to an optical projector. It should be made clear that the projector serves the same fundamental purpose as the toolmaker's microscope, and its advantages are solely practical in that it produces a real image which can be seen on a screen instead of a virtual image which can be seen only by looking through an optical system (i.e., a microscope). Programming is now simply a numerical control system worked in reverse, with a human operator closing the feedback loop. The master-board (or a photo-copy of it) is attached to the table of the projector, and the table is positioned manually by the operator, after which the position is recorded on magnetic tape. When a board is being drilled, the numerical commands on the magnetic tape bring the table to its various positions. The Micro-path programmer, as a positioning aid to the operator, includes a joy-stick whose magnification of movement can be varied by altering its length. In this way, both delicate final positioning and rapid traverse can be achieved satisfactorily. Obviously, since the programmer is effectively a numerical control system, it can be operated the right way round, so that the magnetic tape can be run through the reader and the operator can check that the holes of the master-board come under the cross-lines of the screen; thus, the programmer can act as its own tape verifier.

Economic Aspects

In the previous survey some consideration was given to certain economic aspects of numerical control. These aspects were largely related to numerically controlled machines in isolation and associated with the effect of batch size and programming time on the cost per component. The major points which were demonstrated were (1) the rapid reduction in cost per component when the number of components is in the range of 1 to 5, and (2) the rapidity with which the cost per component levels off, frequently becoming almost asymptotic for a batch of about a dozen components.

What is clearly more important, however, is a comparative assessment of the economics of numerical control in terms of manual control or tracer control. It is not easy to generalize on this question and yet it is clearly most undesirable to need complete costing by both methods before a decision can be made as to which method produces a component most economically. What is required, then, is some criterion by which the most economic method can be assessed as quickly and easily as possible. It must be conceded that speed and simplicity will undoubtedly be bought at the expense of 100% accuracy and, in effect, the utility of the criterion is how closely the accuracy approaches 100%.

With this in mind, an investigation was undertaken by post-graduate students in the author's group at the Imperial College of Science and Technology. Over 600 case studies were conducted in the development division of an aviation company, each study involving the complete costing of a component by manual and numerical control. This was a long and tedious procedure, but was felt to be necessary for the efficient judgment of any criteria proposed.

The effect of batch size as an important factor was discarded at an early stage. The influence of batch size on cost per component is of the same general form for manual, tracer, and numerical control, since all have one element of cost which remains constant (i.e., independent of batch size) and another, due to general preparatory costs, which decreases hyperbolically with an increase in batch size; in other words, the cost per component C is related to batch size N by an equation of the form

$$C = a + b/N$$

where a and b are constants.

Evidently the ratio of a to b will change considerably and it is possible to foresee three possibilities, i.e.,

(1) that numerical control will always be less economic,
(2) that numerical control will remain more economic within the practical range of batch sizes, or
(3) that there is a break-even point, i.e., at some batch size within the practical range numerical control ceases to be the more economic method (this critical batch size can vary by as much as 100 to 300 components).

After the case studies were reviewed, it was decided, in the interest of simplicity, to ignore the effect of batch size and to base all comparisons on a batch of 10 components, accepting that, where numerical control showed a rather marginal advantage, it was likely that a break-even point existed within the practical range of batch sizes.

Consideration was then given to what it was that made numerical control so advantageous for some components. The answer was clear enough—complexity—but the problem was how to express complexity quantitatively. Various functions were considered, including the amount of metal removal and the machining time. The first of these was rejected as unrepresentative, because it was not difficult to imagine two components requiring the same amount of metal removal which would, however, have very different complexities. The length of time spent in machining was, on the other hand, thought to be promising as a criterion.

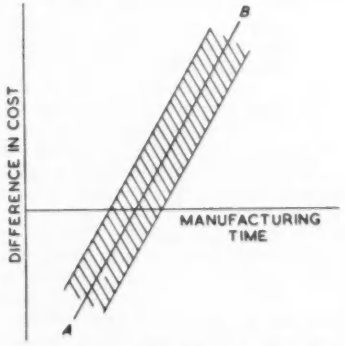


Fig. 34. Anticipated correlation between the difference in cost and machining time.

The difference in cost between manually and numerically controlled machining was then determined for each component, and this difference was plotted against machining time. The author and his co-workers did not anticipate that the correlation would be 100%, i.e., that every point would lie along one line, such as *AB* in Fig. 34, but they did hope that all points might lie inside a reasonably narrow band, such as that shown

shaded in Fig. 34. However, the correlation coefficient for *all* data proved to be less than 0·2 and, even when the data were differentiated, the correlation coefficient for continuous contour control was only 0·35, while that for positional control was even worse, i.e., 0·14, confirming a previous suspicion that it would be more difficult to generalize on positional control than on continuous contour control. In fact, the problem of positional control was never satisfactorily resolved, but an alternative approach to continuous contour control proved more successful. The contouring case studies were reviewed carefully and an attempt was made to find factors which favoured numerical control, and *vice versa*. A statistical analysis showed the most important factors to be:

the number of decelerations D,
the number of straight lines A parallel to an axis,
and the number of other curves P which the data-processing medium will handle as non-generic curves.

The analysis also showed that the following two criteria gave a 95% confidence limit, i.e., that a numerically-controlled machine has the economic advantage

when either $D > 25$ and $A < P$,

or when $A > 50$.

These criteria are shown graphically in Fig. 35.

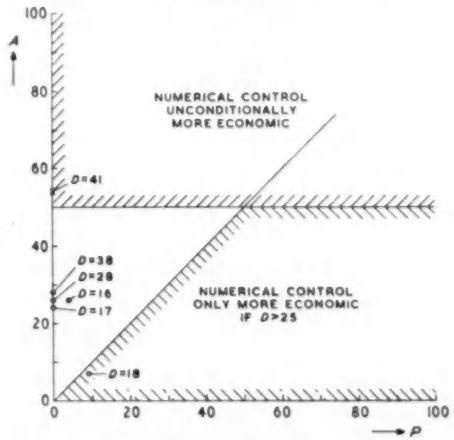


Fig. 35. Graphical representation of the Millyard-Brewer criteria for the economic advantages and disadvantages of continuous contour control systems.

The details of a random sample of 36 of the case studies have been given by Millyard and Brewer[17]. Of these, 30 were unqualified successes for the criteria in that 19 correctly predicted that numerical control was more economical, while 11 correctly predicted against numerical control. The failure cases also shown in Fig. 35, are perhaps more interesting, five of them failing to show that numerical control was more effective, as indicated by the open circles, although, in four cases out of five, the savings were not insignificant. In one final case, the criteria indicated that numerical control was more economical, although it was, in fact, almost twice as expensive (shown by a cross in Fig. 35). It will be noted, however, that all six points representing failure cases lie on, or almost on, the axis of A, suggesting that cases where the value of P is very small should be treated with greater caution.

On the other hand, there have been some gratifying successes. One component (with 243 decelerations and 192 lines not parallel to an axis) was, as expected, given a decision in favour of numerical control, costing showing a reduction from approximately £57 by manual control to £13 by numerical control. Another component, however, had 610 decelerations and looked a certainty for numerical control, but failed to satisfy the condition $A < P$. When the cost figures were consulted, it was seen that manual control at £2 was very much cheaper than numerical control at £33. Indeed, this component is an excellent example of the fact that a high number of decelerations in numerical control does not necessarily mean a highly complex component when produced by manual control.

There have been some opportunities since the original investigation to check the criteria in other manufacturing companies. The results have confirmed that the criteria proposed form a reasonable compromise between tedious costing work on the one hand and the lack of reliability associated with near-guesswork on the other.

Apart from isolated cases quoted in advertisements, there is still little information on the economics of numerical control. In this connection, the data collected at the Royal Ordnance Factory, Nottingham, on four components and presented by Pull[18], although not extensive, is of interest. However, it is clear that much more economic information is needed, especially on positional control, not only to help in deciding which components to machine on controlled machine tools, but also to help in deciding whether to buy numerical control in the first place.

The Machine Tool

Since the appearance of the previous survey, many projects connected with machine-tool structures have been started or intensified. The work of Tobias on vibrations of machine tools has been accelerated by a Ministry of Aviation grant which has enabled staff and laboratory facilities to be increased, and analytical and graphical procedures have been developed for investigating the natural modes of vibration. Following his earlier work with Fishwick[19], Tobias has continued to regard the cutting process itself as being dynamic in nature, i.e., he regards the cutting force as being influenced by the rate of tool penetration into the work, as well as the mean level of penetration (chip thickness).

This model of the cutting-force variation is somewhat complex, and Tobias and Fishwick limited their consideration of the machine tool to cases where the modes of structural vibration were separated sufficiently to permit their interaction to be neglected. By making the rather simpler assumption that cutting force is proportional to chip thickness, Tlusty and Polacek[20] were able to consider the machine-tool structure in more detail, particularly with regard to the superposition of structural modes when determining the relative movement between

(17) P. W. Millyard and R. C. Brewer: "Some Economic Aspects of Numerically-Controlled Machine Tools". *The Production Engineer*, Vol. 39, No. 3, p. 141.

(18) J. H. Pull: "The Application of Control Systems to Jobbing and Batch Production". *The Production Engineer*, Vol. 40, No. 2, p. 99.

(19) S. A. Tobias and W. Fishwick: "Theory of Regenerative Machine Tool Chatter". *The Engineer*, Vol. 205, pp. 199 and 238.

(20) J. Tlusty and M. Polacek: "Beispiele der Behandlung der selbsterregten Schwingung der Werkzeugmaschinen". Proceedings of the third FoKoMa, Vogel-Verlag, Würzburg, 1957.

tool and workpiece. This research on vibrations is typical of the very good work done by Tlusty and his colleagues at the Institute for Machine-Tool Research in Prague.

Machine-tool vibrations have also been studied experimentally by Koenigsberger at Manchester, by Opitz at Aachen, by Eisele at Munich, and by the author. Dynamic stiffness is dependent on static stiffness, and there is naturally considerable interest in the question of designing machine frames to achieve some specified static stiffness. Several approaches have been made; thus, Koenigsberger has studied frame elements by means of metallic models of somewhat smaller dimensions, while Brown (of the Staveley Organization) and Opitz have built small perspex models of complete frames, and the author has made a theoretical approach to the question.

Koenigsberger's project at Manchester, which was first supported by the National Research and Development Corporation, is now assisted by the Department of Scientific and Industrial Research (D.S.I.R.), and many aspects of machine-tool design are being investigated, including the use of an optical reference system for compensating inherent errors in the machine-tool elements. Initial work in this field has been very successful, and it is intended to acquire a very old machine to subject the method to as exacting a test as possible.

Last year saw the first of a series of annual Machine-Tool Research and Design Conferences at Birmingham University. This year's conference is at Manchester, and many papers on machine-tool design are scheduled for presentation. These conferences will undoubtedly perform a valuable service as a clearing-house of ideas, and it is to be hoped that the machine-tool industry will avail itself of the published information.

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Karl Hüller G.m.b.H., Ludwigsburg, Germany.

International Business Machines Corporation, 590 Madison Ave., New York 22, N.Y., U.S.A.

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Siemens Schuckert-Werke, Erlangen, Germany.

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Société d'Electronique et d'Automatisme, 138 Boulevard de Verdun, Courbevoie (Seine), France.

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Wadkin Ltd., Green Lane Works, Leicester.

Warner & Swasey Research Corp., 34 West 33rd St., New York 1, N.Y., U.S.A.

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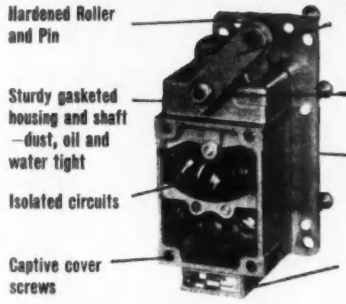
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Sturdy gasketed housing and shaft —dust, oil and water tight
"O" Ring shaft seal
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Captive cover screws
Plug-in available

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LONG CONTACT LIFE Lowest impact, minimum "bounce". Weight of contact units (mass at impact) 2.45 grams.

70° SAFETY OVERTRAVEL

WATER, DUST AND OIL TIGHT

MEDIUM OPERATING FORCE Greatly reduced wear.

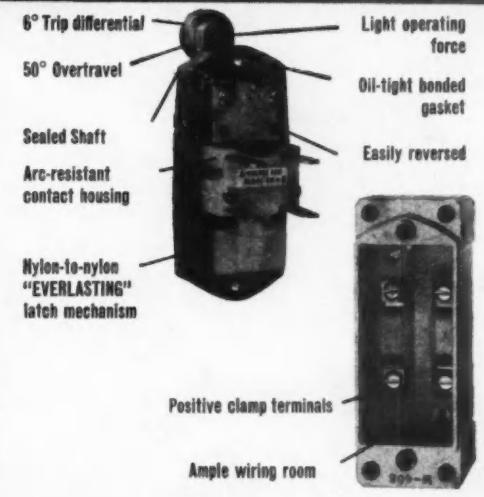
SIMPLICITY OF DESIGN Ease of maintenance, few working parts.

INTERCHANGEABILITY Switch mountings and levers fit most existing installations.

LEVERS 150 levers available.

45 CONTACT ARRANGEMENTS

MODEL M *precision*



LONG MECHANICAL LIFE Heavy duty nylon latch mechanism. Tested to 45,000,000 cycles under electrical load.

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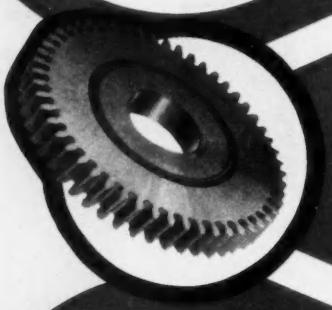
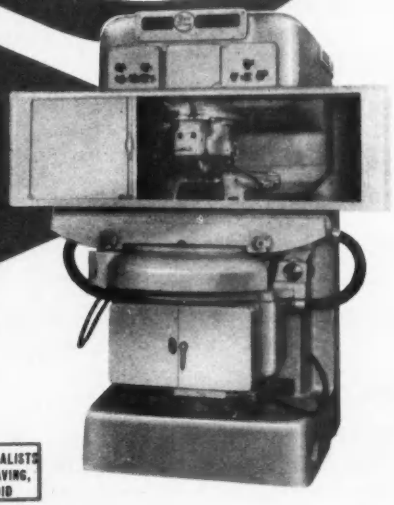


. . . . by a Gear Shaving Cutter

. . . . on a Model G.C.U. Gear Shaving Machine



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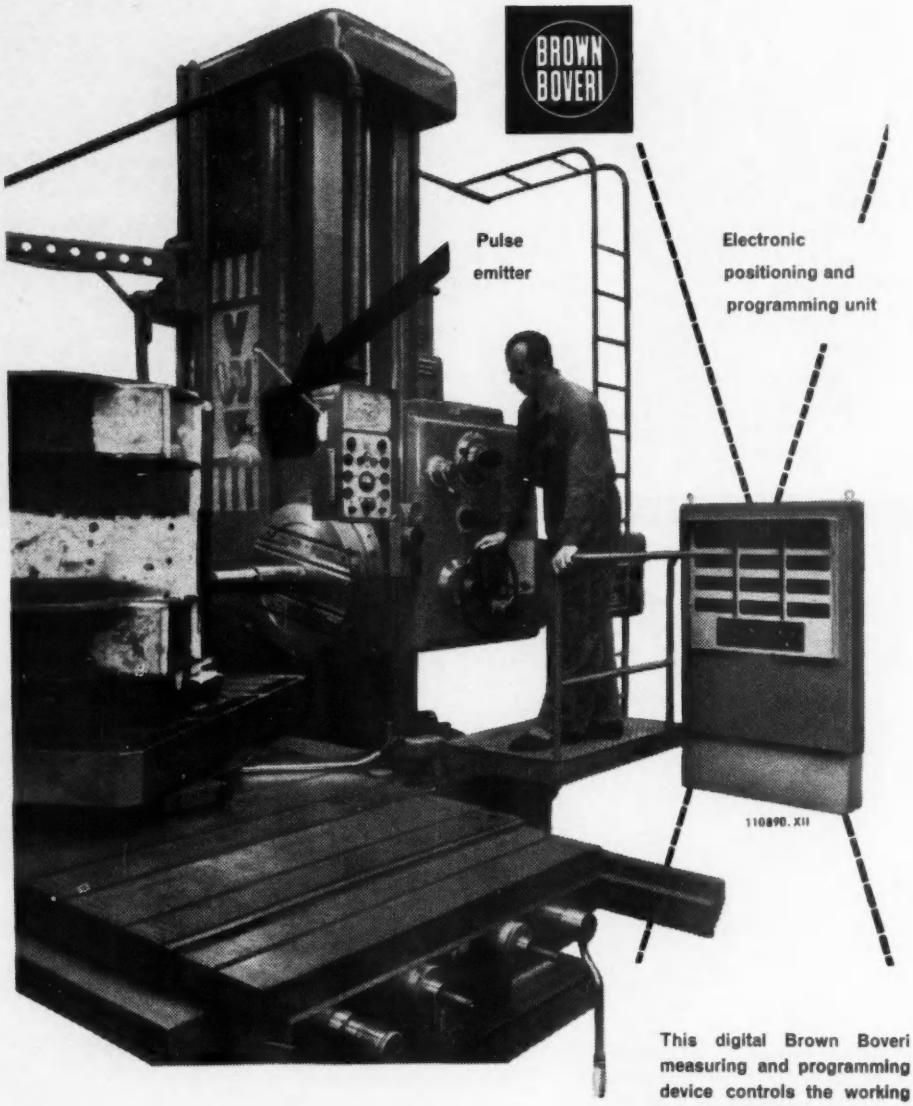

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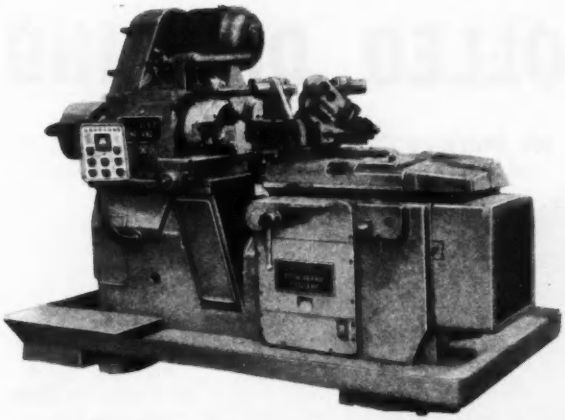

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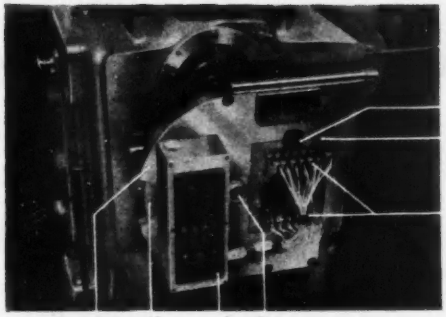

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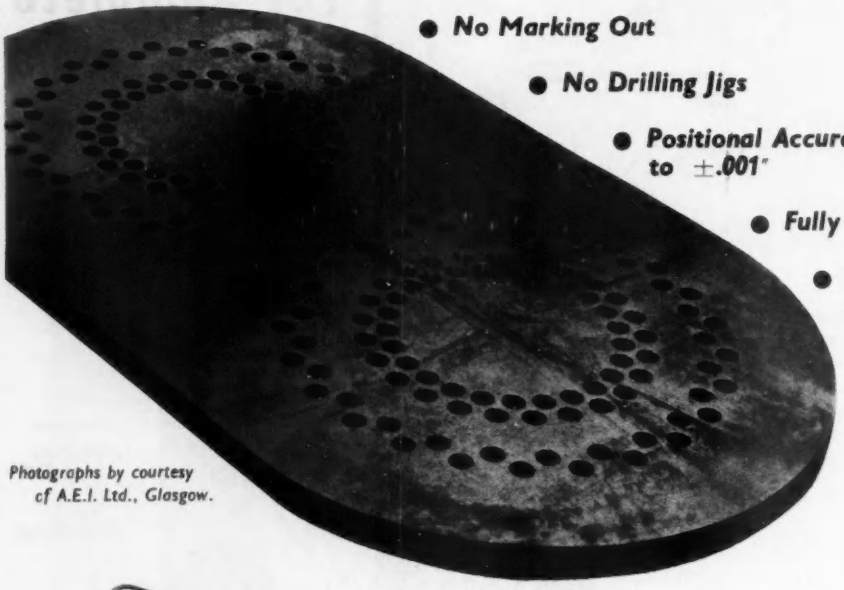

- No Marking Out
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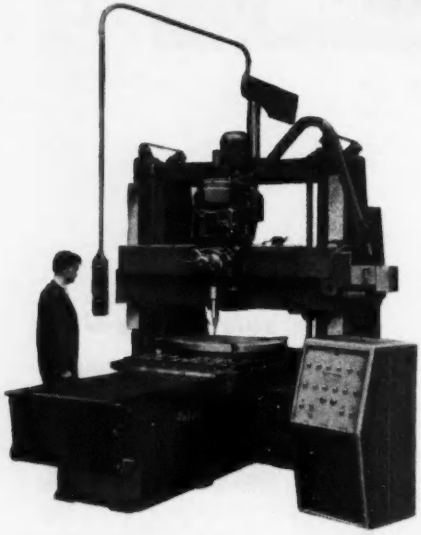
- Positional Accuracy to ±.001"
- Fully Automatic
- Tape or Dial Setting

Photographs by courtesy of A.E.I. Ltd., Glasgow.



Wadkin Positional Drilling Machine T.C.D.1

This machine will accurately position holes up to 2 in. diameter in steel. It eliminates all marking off as well as the necessity of using drilling fixtures. Once the tape has been punched—a relatively simple operation—exact repetitions of even the most complicated drilling jobs are guaranteed at any time. The rigidity of the machine enables maximum diameter drills to be fed directly into steel without the break-through problem normally experienced. The price of this machine, complete with positioning control system, compares favourably with a conventional drilling machine of the same capacity. Either single or multi-station turret heads can be fitted. May we send you more details?

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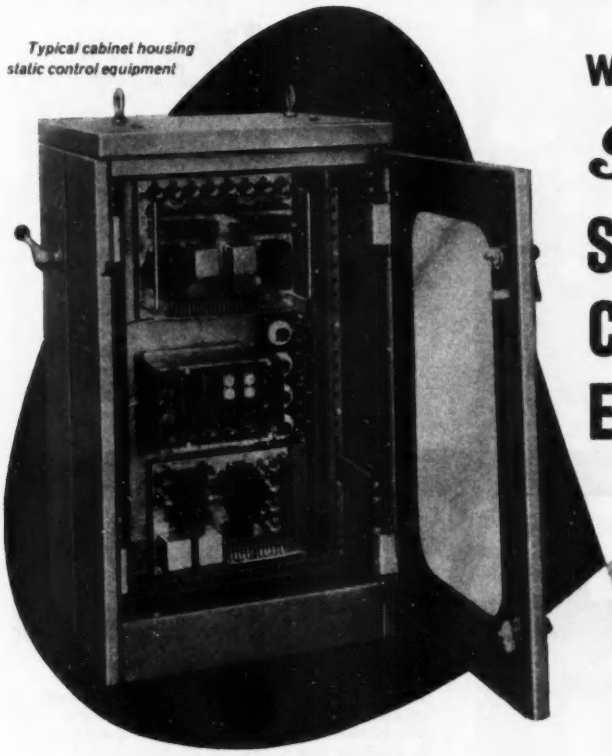
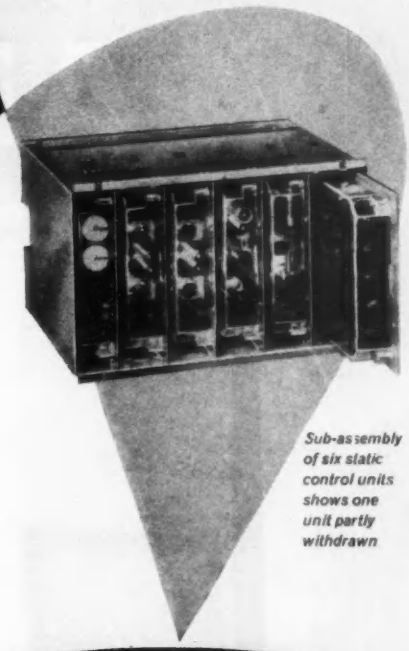


Typical cabinet housing static control equipment

with

G.E.C.

STATIC CONTROL EQUIPMENT



Sub-assembly of six static control units shows one unit partly withdrawn

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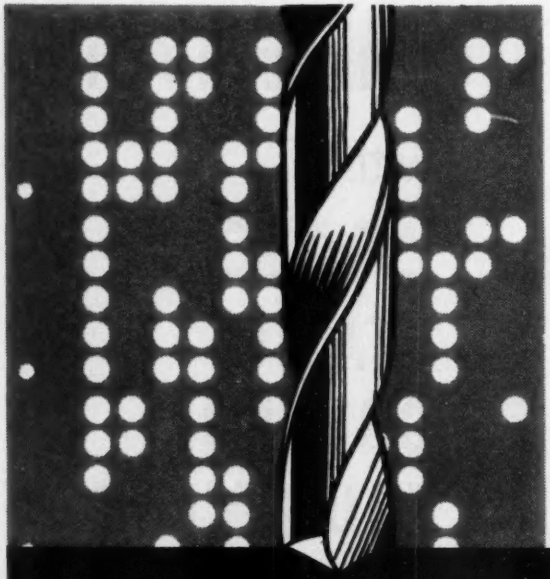

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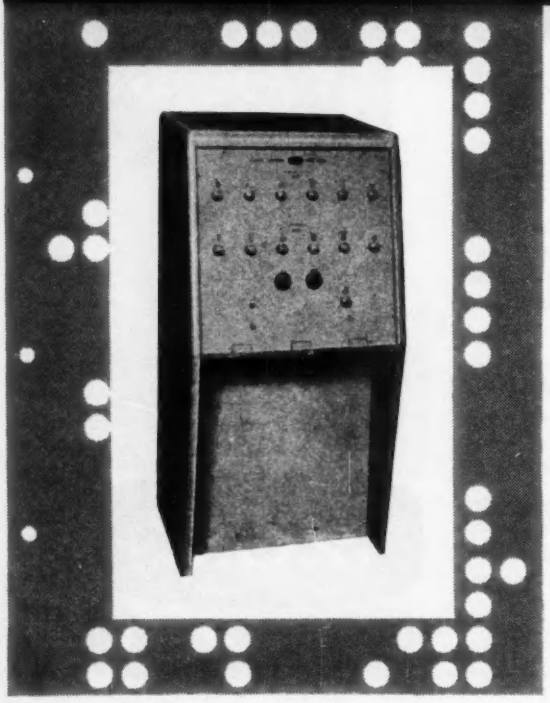

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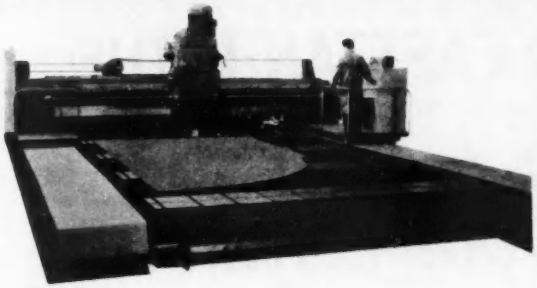
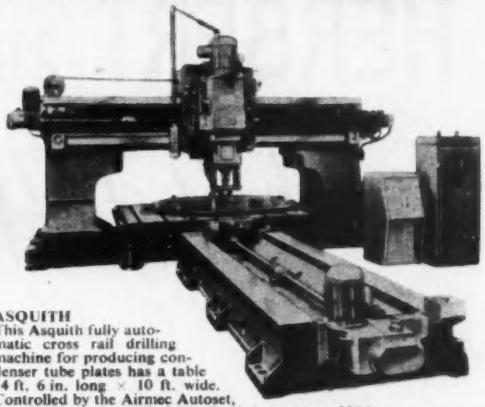


WADKIN
This Wadkin fully automatic drilling machine type TCD 2 has a table capacity of 20 ft. 0 in. × 14 ft. 0 in. Controlled by the Airmec Autoset, the overall accuracy of positioning is better than ±0·01 in.
Manufacturers: Wadkin Limited, Green Lane Works, Leicester.



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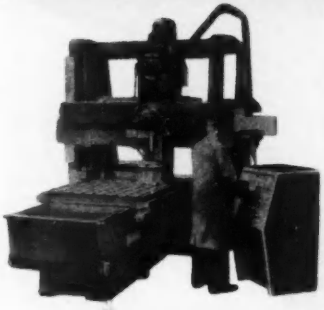
Full details available from: William Asquith Ltd., Highroad Well Works, Halifax, Yorks.

AUTOSET



WADKIN
Autoset fitted to Wadkin TCD1. Full details available from: Wadkin Ltd., Green Lane Works, Leicester.

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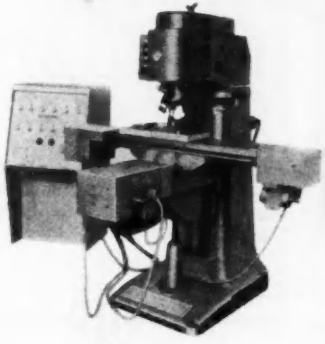

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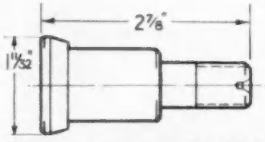

This component machined from free cutting mild steel is produced in a time of 2 minutes

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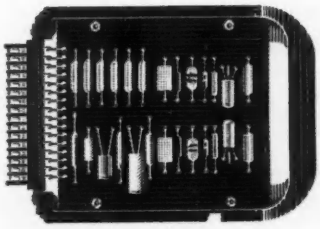

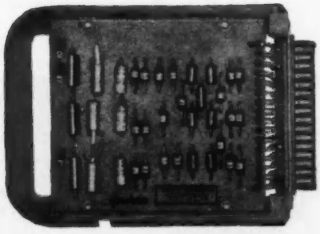

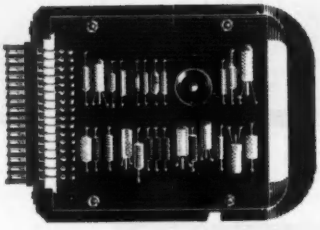

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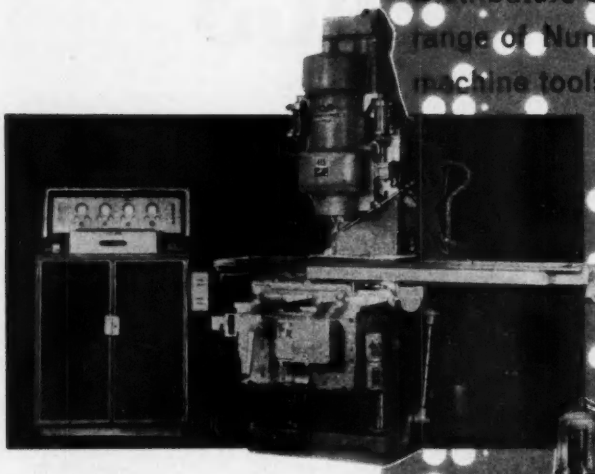

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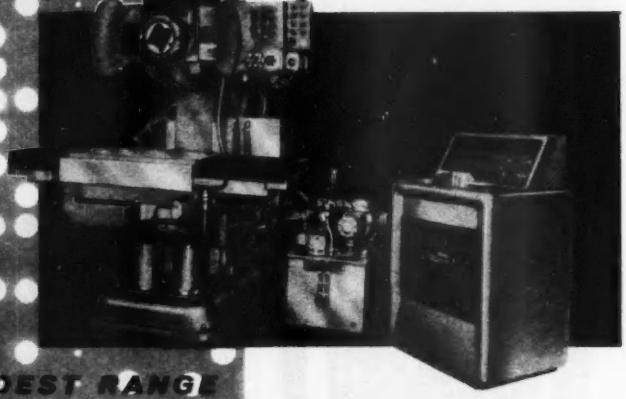

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A World Review of DESIGN & PRODUCTION — RESEARCH & DEVELOPMENT

VOL. XXII No. 8 AUGUST, 1961

Bimetallic Pipes

By D. CHRISTOPHER

From *Mechanical Engineering*, U.S.A., Vol. 83, No. 6, June 1961, pp. 68–72, 10 illustrations.

MANY kinds of bimetallic pipe are now made by a variety of methods, each kind being suitable for some particular applications, though none can be considered as a panacea for all corrosion problems. Of these materials, cold-drawn bimetallic tubing is probably the best known, because of its extensive use in condenser and heat-exchanger service, though large sizes of pipe made from clad sheet or plate are also quite well known.

In the type of product discussed in this article, a lining material is hydraulically seated into a base pipe. This system utilizes the most inexpensive and the most readily available material for both base and lining. Generally, standard steel pipe is the base in standard pipe sizes and schedules. The lining for the small sizes is usually seamless or welded thin-wall alloy tubing; in the large sizes, the linings are welded from alloy sheet. The completed product is low in final cost. At present the size range is from 1 to 20 in. in diameter in every standard wall and lining thickness desired.

In the method of manufacturing bimetallic pipe used by the author's company, a relatively thin lining of alloy material is hydraulically expanded into a base pipe. With the correct selection of the initial diameters of the base and lining materials, and by proper application of pressure, the lining expands with a uniform yield until it just contacts the base pipe. Pressure beyond this initial level elastically expands the base pipe and continues the plastic expansion of the lining. After the final pressure is released, the elastic contraction of the base material actually exceeds that of the contraction of the lining material, thereby holding the lining tightly in place and effectively applying a slight compressive force. If the initial seating pressure is not sufficient to produce a stress in the base pipe equal to the stress in the lining, then the lining will never be completely tight. Conversely, any additional stress in the base beyond that in the lining will ensure a tightly lined finished product.

Differences in the modulus of elasticity will have some effect on the resulting product. Most of the alloys and materials used in making bimetallic pipe have a modulus of elasticity ranging from 25×10^6 to 30×10^6. This relatively small difference from one metal to another will have little effect on the ability of the material either to stay tight or become loose when it forms a lining. Four metals, however, have considerably lower moduli of elasticity, these being copper, aluminium, titanium, and zirconium. With these metals, the slope of the stress-strain curve in the elastic range will make a slight difference in the tightness of the lining. If a low modulus of elasticity is coupled with a low yield point (as in aluminium and copper), springback will not be serious. On the other hand, a low modulus coupled with a high yield point will require careful control. To overcome springback, heating to reduce yield strength can be effective.

Whether this piping material is drawn through a die, ball-expanded, rolled, or hydraulically expanded, these same fundamental premises must be held in order to achieve a tight assembly. In operation, the pipe will stay tightly in contact with the base if there is a positive pressure differential between the inside and the outside, and/or the inside is greater than the outside temperature. Of course, the differential in thermal expansion will have something to do with this tightness over any temperature range, but this difference is of a very small order, representing between copper and steel approximately 0·2 micro-inch per inch per °F. With a temperature change of 100°F, a copper-lined pipe, 3 in. in diameter, could become loose by 0·00006 in. or tighter by the same amount. This factor can exist only if there is no residual compression in the manufacture.

This variation in thermal expansion takes on greater significance in analysing the possible effect in endwise expansion and contraction. The longest pipe which it is now practical to make with this system would be approximately 40 ft, and it is impossible to project this differential from one joint to another. Each joint of pipe would have the lining clamped or sealed by welding at the ends, so that axial movement of the lining cannot be transmitted along the line from joint to joint. If a temperature change of 1000°F were applied to a 20-ft length of pipe, the variation in expansion of one piece could amount to 0·48 in. If the lining were free to move axially, such an expansion or contraction might cause some trouble in the operation of the piping system. Counteracting this thermal force, however, is a frictional component which will take care of the thermal stress by converting it into a tension or compression stress.

In the author's experience, no relative movement has been noted in examining the cut ends of pipe which have been heated in bending. A careful check has been made of a 16-in. diameter pipe in joints of 24 ft length, heated in the centre to 1950°F. Even under these severe conditions, the lining adhered tightly to the pipe.

From applied pressure and strain measurements, it is known that the lining material adds considerably to the overall strength of any base pipe, which will be stronger in resistance to internal pressure and will also be stronger in resistance to normal bending forces. The relevant code, however, does not recognize this additional strength consideration, and any calculations regarding pressures must be based on the material from which the base pipe is made and its wall thickness.

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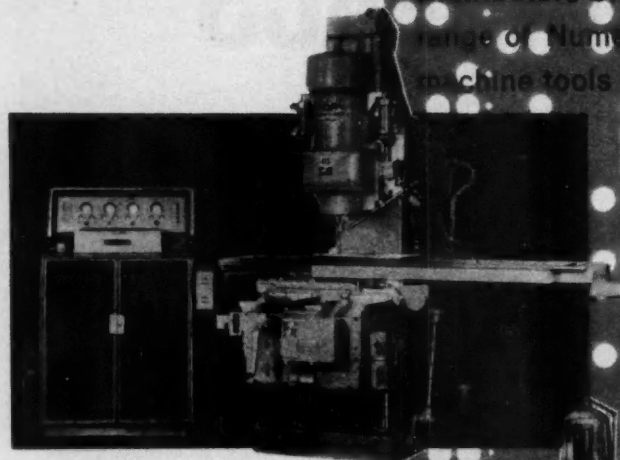

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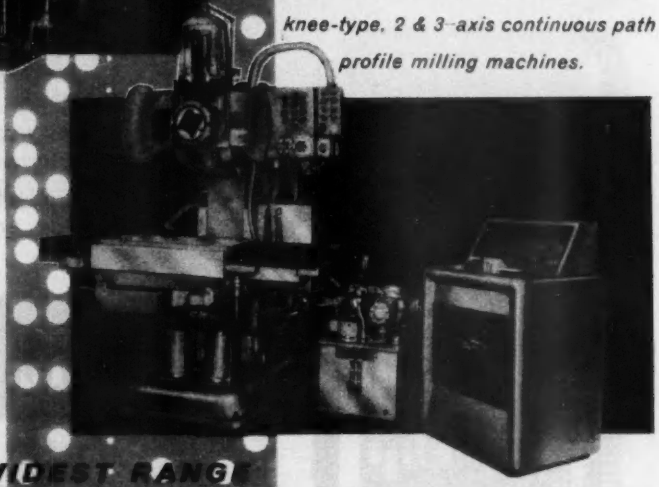

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Bimetallic Pipes

By D. CHRISTOPHER

From *Mechanical Engineering*, U.S.A.,
Vol. 83, No. 6, June 1961,
pp. 68–72, 10 illustrations.

MANY kinds of bimetallic pipe are now made by a variety of methods, each kind being suitable for some particular applications, though none can be considered as a panacea for all corrosion problems. Of these materials, cold-drawn bimetallic tubing is probably the best known, because of its extensive use in condenser and heat-exchanger service, though large sizes of pipe made from clad sheet or plate are also quite well known.

In the type of product discussed in this article, a lining material is hydraulically seated into a base pipe. This system utilizes the most inexpensive and the most readily available material for both base and lining. Generally, standard steel pipe is the base in standard pipe sizes and schedules. The lining for the small sizes is usually seamless or welded thin-wall alloy tubing; in the large sizes, the linings are welded from alloy sheet. The completed product is low in final cost. At present the size range is from 1 to 20 in. in diameter in every standard wall and lining thickness desired.

In the method of manufacturing bimetallic pipe used by the author's company, a relatively thin lining of alloy material is hydraulically expanded into a base pipe. With the correct selection of the initial diameters of the base and lining materials, and by proper application of pressure, the lining expands with a uniform yield until it just contacts the base pipe. Pressure beyond this initial level elastically expands the base pipe and continues the plastic expansion of the lining. After the final pressure is released, the elastic contraction of the base material actually exceeds that of the contraction of the lining material, thereby holding the lining tightly in place and effectively applying a slight compressive force. If the initial seating pressure is not sufficient to produce a stress in the base pipe equal to the stress in the lining, then the lining will never be completely tight. Conversely, any additional stress in the base beyond that in the lining will ensure a tightly lined finished product.

Differences in the modulus of elasticity will have some effect on the resulting product. Most of the alloys and materials used in making bimetallic pipe have a modulus of elasticity ranging from 25×10^6 to 30×10^6. This relatively small difference from one metal to another will have little effect on the ability of the material either to stay tight or become loose when it forms a lining. Four metals, however, have considerably lower moduli of elasticity, these being copper, aluminium, titanium, and zirconium. With these metals, the slope of the stress-strain curve in the elastic range will make a slight difference in the tightness of the lining. If a low modulus of elasticity is coupled with a low yield point (as in aluminium and copper), springback will not be serious. On the other hand, a low modulus coupled with a high yield point will require careful control. To overcome springback, heating to reduce yield strength can be effective.

Whether this piping material is drawn through a die, ball-expanded, rolled, or hydraulically expanded, these same fundamental premises must be held in order to achieve a tight assembly. In operation, the pipe will stay tightly in contact with the base if there is a positive pressure differential between the inside and the outside, and/or the inside is greater than the outside temperature. Of course, the differential in thermal expansion will have something to do with this tightness over any temperature range, but this difference is of a very small order, representing between copper and steel approximately 0·2 micro-inch per inch per °F. With a temperature change of 100°F, a copper-lined pipe, 3 in. in diameter, could become loose by 0·00006 in. or tighter by the same amount. This factor can exist only if there is no residual compression in the manufacture.

This variation in thermal expansion takes on greater significance in analysing the possible effect in endwise expansion and contraction. The longest pipe which it is now practical to make with this system would be approximately 40 ft, and it is impossible to project this differential from one joint to another. Each joint of pipe would have the lining clamped or sealed by welding at the ends, so that axial movement of the lining cannot be transmitted along the line from joint to joint. If a temperature change of 1000°F were applied to a 20-ft length of pipe, the variation in expansion of one piece could amount to 0·48 in. If the lining were free to move axially, such an expansion or contraction might cause some trouble in the operation of the piping system. Counteracting this thermal force, however, is a frictional component which will take care of the thermal stress by converting it into a tension or compression stress.

In the author's experience, no relative movement has been noted in examining the cut ends of pipe which have been heated in bending. A careful check has been made of a 16-in. diameter pipe in joints of 24 ft length, heated in the centre to 1950°F. Even under these severe conditions, the lining adhered tightly to the pipe.

From applied pressure and strain measurements, it is known that the lining material adds considerably to the overall strength of any base pipe, which will be stronger in resistance to internal pressure and will also be stronger in resistance to normal bending forces. The relevant code, however, does not recognize this additional strength consideration, and any calculations regarding pressures must be based on the material from which the base pipe is made and its wall thickness.

It would be unreasonable to assume that two pieces of metal squeezed together in any way would possess equivalent heat-transfer properties to that of solid metal. In general, if the heat-transfer characteristics of the base and the lining material are drawn on one chart, the

heat-transfer characteristics of the bimetallic pipe lie between these two curves.

The first limitation, besides the characteristics of the metal, in obtaining effective heat transfer is the matter of contact between the base and the lining. Even with proper manufacturing techniques, good contact can only be effected if the surfaces are clean. Certainly, contaminants of any sort, including oxides, may possess poorer heat-transfer properties than the base or lining.

Probably the most important factor influencing the total contact is the surface roughness of the tubes. If the mating surfaces have irregularities of considerable magnitude, 100% contact is impossible. If the surfaces are mirror-bright and vary by 10 micro-inches or less, the contact area should be very good, but under no condition will it be 100%. Heat transfer by conduction will be a function of the amount of contact, plus the transfer by radiation across the areas not in contact. It has been suggested that, to improve heat transfer, this interface section should be bathed in a low-molecular-weight gas, such as helium, or possibly even a third metal, such as tin, which might be liquid under some temperature conditions. Actual test data are limited, and the matter may be worthy of further investigation.

Actually, the film coefficient of heat transfer may be greater than the total conductivity of the tubes, and the fouling factors existing in many heat exchangers further reduce this loss to the point of insignificance. In some installations, the ability of the bimetallic tube to resist corrosion and fouling has actually improved the overall heat transfer of some equipment.

Bimetallic pipe attempts to save money by substituting an inexpensive base material (carbon steel) for an expensive alloy. To meet more difficult environmental conditions, the base requirements are, however, sometimes more stringent than those for the lining.

For lining materials, there is a wide choice. From the manufacturing standpoint the best would be a soft, inexpensive, no-yield-point product such as lead, but unfortunately such a material seldom meets the needs of the user, and the most popular are therefore alloys of copper and nickel, ranging from pure copper to pure nickel. These materials do not embrace all the corrosion-resistant properties desired in some cases, so that the austenitic stainless steels are next in order of demand. Experimental work is being carried out with titanium, tantalum, and zirconium, each of which holds considerable promise for future needs.

The use of the least practical amount of expensive material represents the second objective in saving money, but extremely thin linings cannot be used in many applications, and the cost of the lining material per foot is by no means directly proportional to its thickness. In pipe sizes of from 2 to 6 in., linings of 0·035 in. now represent a combination of an economical and a practical minimum, offering adequate corrosion protection and sufficient mechanical strength for most conditions. Linings may be reduced to 0·010 in. if the finished product does not have to be welded, and they have been as heavy as 0·078 in. for pipe up to 16 in. diameter. Pipe sizes up to 4 in. can usually be furnished with seamless linings; in sizes of 4 in. and larger, welded linings are essential. If a very thin lining is required, regardless of the diameter, a welded material represents about the only solution currently available.

Bimetallic pipe fabrication is the same as that for carbon-steel pipe, with some minor refinements. Pipe bends from 5 to 8 diameters can readily be made. Expansion loops and large-radius bends in small sizes of pipe can frequently be made cold but, in large pipe and in heavy-wall sections, the pipe must be heated prior to bending. Heated bends are sand-packed, and the normal precautions for bending pipe for the particular size involved should be followed. Special care must be taken with some metals, and the bending characteristics of the lining, as well as of the base pipe, must be considered if the lining is not to be damaged during bending.

Welding fittings, such as ells, are now obtainable only in solid alloy in small sizes. Large sizes can be individually strip-lined, but a full-lining system for both ells and tees is being developed. To reduce the expense of fittings, particularly in large sizes, mitre bends and "stab-in" tees are most easily made and are quite effective, unless pressure drops or high-velocity requirements preclude their use.

Lined pipe can be effectively butt-welded, the welding procedure varying to some extent with the type of lining used and the size. The most effective butt weld will be one in which there is no possible contamination of the seal weld of the lining by the base material. This is most easily achieved by allowing the lining to extend from the bevel of the pipe by about $\frac{1}{8}$ in. For the irregular shapes used for stab-ins, Y-branches, etc., flame-cutting can be effectively used. In making butt welds the two pieces of pipe with the lining projecting are properly aligned, and the seal pass is made either by straight fusion-welding with inert-gas equipment or with inert-gas welding with a filler wire of the same metal as the lining.

After the seal pass is made, the weld can be completed from the outside by using inert-gas bimetallic welding technique to fuse the lining to the base pipe. After a sufficiently thick weld is deposited to be unaffected by some slight degree of porosity, the weld can be completed by the electric-arc method. In the nickel-base alloys, a bimetallic rod is frequently most successful.

If the pipe wall is irregular in thickness and also for applications such as stab-in tees, it may not be practical to line up the extended lining. A successful seal weld can be made by first buttering the ends of the bevel so that a seal is made between the end of the pipe and the lining material. In large-size pipe and particularly near the ends, the procedure can be reversed, and the technique followed can be similar to that of welding clad-sheet material from the steel side. A welded connection can be produced by either the standard electric arc or by submerged-arc welding, and the seal pass made last. The strength weld must be carefully ground out and cleaned up prior to making the seal weld, which must be produced with the inert-gas method. Several methods can be used for cleaning up and routing out the groove for the seal pass, but the lining can be contaminated by the simple grinding method frequently used.

Various methods of terminating a pipe are available. Of these, the use of lap-joint stub ends is very practical when they are made from the same material as the lining. However, the least expensive method involves the use of faced flanges, which are usually made of a standard carbon steel with a weld-deposited facing subsequently machined to the dimensions of the original flange.

The wide range of sizes in which bimetallic pipe may be made makes quite practical the use of this material for vessels, and its availability, even in limited quantities, frequently enhances the delivery of such equipment. The effective sizes in which bimetallic pipe can be made are more a problem of economics than of engineering.

Solid-Film Lubricants for Extreme Environments

By B. D. McConnell
From *Product Engineering*, U.S.A.,
Vol. 32, No. 24, June 12, 1961,
pp. 70–73, 4 illustrations.

Solid-Film lubricants are now widely used in slow-sliding bearings operating under loads of from 2,000 to 80,000 psi with ambient temperatures of from 450 to 500°F. Although it is true that greases and oils can operate satisfactorily under these conditions, solid-film lubricants offer the considerable advantage of life lubrication of the part. Another possible advantage is the expectation that solid-film lubricants can operate in extreme-temperature environments and under a vacuum, and they seem to be showing considerable promise for such applications.

Commercially available solid-film lubricants are composed of a friction-reducing pigments, a bonding agent (in most cases, an organic adhesive), and a thinning solvent, to give the proper consistency for application. This mixture is applied by brushing, dipping, or spraying to a metallic bearing surface which has been pretreated in some fashion to increase the adhesive bond between the metal and film. Of these three methods of application, spraying is used almost exclusively because of the better control of uniformity in film thickness. The relative merits of one film over those of another depend not only on the vendor, but also on the pigments selected, the binders used, the ratio of the two to each other, etc. Many competing films are very similar in composition.

The lubricating pigments in these films are almost entirely graphite and molybdenum disulphide. Some films are composed of one or the other of these pigments, while others contain a mixture of the two. For a mixture, the practice has been to use approximately 80 to 90% molybdenum disulphide and the remainder graphite. The contribution made by this small percentage of graphite has not been fully explained, but its effectiveness has been demonstrated in bench evaluation and service application.

Bonding agents consist primarily of organic resins and inorganic adhesives. Organic resins are of the phenolic and epoxy resin types. Epoxy compositions are preferred to phenolic compositions; however, mixtures of the two have sometimes been used. Organic resins will not work above 450°F, when thermal degradation begins and wear life falls off rapidly with increasing temperature. The operating temperature of these films can be extended with an inorganic binder, such as a metal matrix composition or ceramic, the top temperature being primarily limited by oxidation of the pigment itself. Molybdenum disulphide suffers severe oxidation at temperatures above 750°F, while graphite is stable to approximately 1000°F, but fails because of loss of absorbed water.

Surface pretreatment is almost as important as film composition. For ferrous metals, the treatments include vapour and grit blasting, and iron and manganese phosphating. Grit and vapour blasting are purely mechanical treatments of the metal surface to create a roughened area, giving the binder material more surface-area contact and hence increasing adhesion.

Phosphate treatment shows the greatest influence in increasing wear life, but is limited to metallic substrates of iron and steel. The phosphating procedure requires special care in application. Lack of rigid control of the bath conditions is believed to be one of the main reasons for the wide variance of wear life from batch to batch—sometimes even within a batch. Temperature must be controlled to within 5 to 6°F of the optimum temperature to ensure proper crystal deposition.

Another deficiency in the phosphate pretreatment is its temperature limitation. Thus, since phosphating is apparently unsatisfactory above 600°F, mechanical treatment of the surface, e.g., by grit or vapour blasting, must be used, unless a better high-temperature pretreatment is developed for these temperatures.

In an effort to find a lubricant suitable for use at temperatures above 1000°F, a survey of more than 22,000 compounds has been conducted. This list was eventually reduced to 16 films having the necessarily high melting point and a hardness not exceeding 4·0 on Moh's scale, together with good oxidation stability in air and reasonable friction characteristics. The most promising film so far developed for operation at 1000°F is a pigment of lead sulphide (PbS) bonded with boric oxide (B_2O_3). The wear life of this film is outstanding at 1000°F, but suffers at lower temperatures, when there is also a deterioration in friction characteristics. Other tests indicate that the binder in such a composition influences lubricity and wear life much more than was originally considered. Various other pigments were tried with boric oxide, but the results obtained were not as good as those with lead sulphide, and in many cases the coefficient of friction and wear rate were high.

The performance of the films of lead sulphide and boric oxide at 1000°F has prompted current efforts to improve wear life at room temperature. Additions of graphite to the film produced very little improvement in its performance at any temperature, while molybdenum disulphide (MoS_2) resulted in an outstanding improvement in the wear life at room temperature but had a detrimental effect at high temperature. The best results to date have been films with a lubricant mixture of 67% molybdenum disulphide and 33% lead sulphide.

The effect of polishing and liquid-honing the races has also been studied, and preliminary results indicate that a substantial improvement in wear life is obtained at 700°F when a film of PbS-MoS_2-B_2O_3 is bonded on a liquid-honed substrate.

Precoating the races with B_2O_3 before applying the lubricant film had no significant effect on steel, but was found to be essential for titanium races. Films of MoS_2-B_2O_3 on titanium failed on loading with no precoating, but had an average life of 45,000 revolutions at room temperature with a B_2O_3 precoating.

Insofar as the properties of different films in a vacuum are concerned, tests showed that graphite films had wear lives of only 10% of their average values in air. This drastic reduction in wear life may be caused by the behaviour of graphite in an atmosphere in which the partial pressure of water vapour is very low. The wear life of molybdenum disulphide bonded with boric oxide was found to be comparable with that obtained in air.

The three-component PbS-MoS_2-B_2O_3 system was also tested in a vacuum, using various combinations at temperatures of 400, 700, and 1000°F. It was found that films containing a low proportion of B_2O_3, compared with either PbS or MoS_2, had low wear lives at all temperatures. The best wear-life results in a vacuum so

far obtained were produced with a film containing 67% B_2O_3 and 33% of PbS and MoS_2, which, under a 100-lb load, had a wear life of 4,000 revolutions at 1000°F, 20,000 revolutions at 700°F, and over 200,000 revolutions at 400°F.

The requirement for lubrication at 1000°F has now been pushed up into the range of 1500 to 2000°F. At these temperatures available substrate metals approach their limit in strength and oxidative stability. Present solid films will no longer operate, and new pigments, as well as bonding agents, will have to be developed. New bearing materials will have to be produced and made compatible with lubricating systems, and new concepts in lubrication will be derived. Perhaps the so-called dry lubrication methods will be effective at these temperatures.

A vacuum wear-tester, with temperature capabilities above 1500°F, is now being constructed. Compounds with melting points and thermal stability above this temperature are being screened for possible lubricating pigments, and bonding techniques are being investigated. A programme has recently been initiated for investigating lubrication and bearing design for operation at 2000°F, and some of the compounds of beryllium, columbium, and other metals are being studied as possible bearing materials. In addition, equipment has been designed to cater for friction and wear tests at 2000°F.

A Multi-Polarized Space-Scanning Antenna for Missile Tracking

A NEW multi-polarized antenna which can do the work of four separate types of antennae for space-scanning or missile-tracking has been developed by the Electronics Division of the Chance Vought Corporation. These units, which are based on the principle of dual-linear telemetry, are being installed on the U.S.N.S. "Range Tracker" (Fig. 1), which is stated to be the most completely equipped missile-tracking ship in the world.

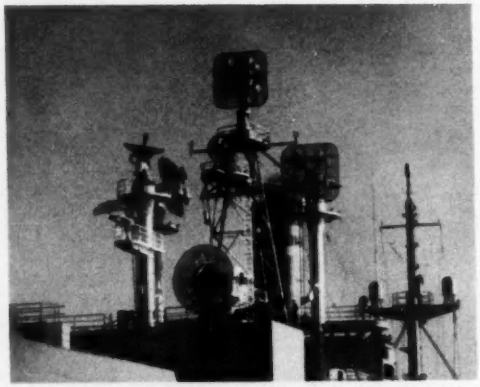

Fig. 1. Close-up of an array of multi-polarized antennae units on the U.S.N.S. "Range Tracker".

By means of simple switching, the antenna can be polarized vertically, horizontally, or circularly, with either clockwise or anticlockwise polarization, so that it performs the functions of four separate antennae of the normal type. The polarity best suited for operation with a particular missile or space vehicle is selected by remote switching or, if necessary, automatically, change-over being effected immediately.

When designing antenna systems for missiles or satellites, it is usual to select linear polarization as providing the best all-round coverage pattern. However, with the complex shapes of the newer missiles and satellites, it is extremely difficult to generate pure linear polarization. At some angles, and when rolling or tumbling, an airborne system can produce the desired and other polarizations, yielding at the ground station a mixture of vertical and horizontal polarization and elliptical polarizations of both right-hand and left-hand sense. Thus, the ground station requires an antenna which is capable of receiving all polarizations. The new antenna is adapted to these different polarizations by remote switching or by connecting various cabling arrangements at the rear of the ground screen, and the difficult element-changing of conventional arrays is eliminated.

The multi-polarized array is mounted on a ground plane of the same size as conventional arrays of equal gain, but offers a reduction of 3 : 1 in end-fire length over helical arrays. This reduced end-fire length places the centre of gravity closer to the centre of rotation of the pedestal and makes the antenna less subject to vibration during the maximum slew rates found in tracking.

It was considered that the best design for a multi-polarized antenna would be one with two separate inputs, one for horizontal polarization and the other for vertical polarization, the antenna being polarized circularly by inserting a 90-deg. phase-shift between the inputs. The antenna designed on this basis consists of two full-wave elements, one horizontal and the other vertical, fed from balanced transmission lines. To reduce the high input impedance of centre-fed full-wavelength elements, each of the driven elements is enclosed in a tube for approximately half its length each side of centre, this tube forming a coaxial transmission line. The centre conductor extends out of the tubular section and is flared into a conical shape, providing a broader-band radiator. The outer tube of the coaxial line is connected to a large cylinder at its outer end, so as to maintain proper radiation patterns. A pair of straps from the edge of the outer cylinder to the end of each centre element adds inductance and improves phase relationships.

The end-fire structure, which gives the antenna its characteristic Maltese-cross appearance (Fig. 2), consists of two broadband parasitic elements ahead of each driven section. The sides and ends of the Maltese crosses are made of fibre-glass, as also is the square-shaped plate at the centre of each cross. Thus, each of the eight parasitic elements in each cross is insulated from the others. The elements are spaced in such a way as to act as directors, empirical methods being used to design the structure, and are specially shaped to keep the band wide.

Four of these antennae, mounted on a ground plane

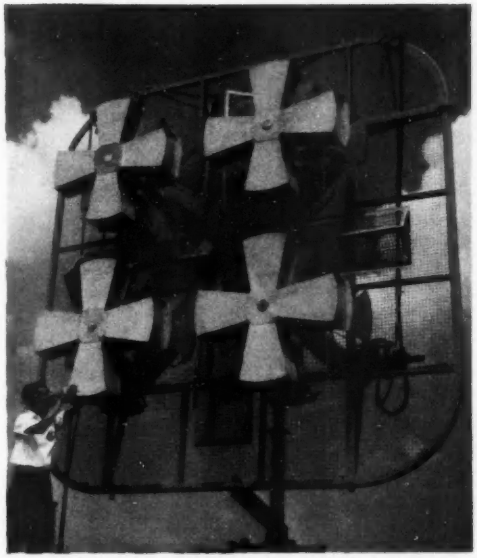

Fig. 2. Close-up of one unit of the multi-polarized antenna.

12-ft square, constitute a typical array, the antennae being mounted one wavelength apart at 215 Mcs. An improvement in side-lobe level has been obtained by adding a structure on the ground plane between the individual antennae, so that each is free from reflections from the others. The resulting U.H.F. multi-polarized antenna has an essentially flat characteristic from 215 to 260 Mcs, a directional pattern of 20 deg. between half-power points, a gain of at least 18 dB, and a voltage standing-wave ratio of not more than 1·5 : 1.

When all four antennae are fed in phase, the array produces a sum pattern ideally suitable for receiving telemetry data. The most common tracking system is one in which the four antennae are fed into a comparator, producing an output consisting of a sum channel and an azimuth and elevation difference channel. The azimuth difference channel places the two azimuthal halves of the antenna 180-deg. out of phase and so produces a deep, sharp null in the direction of the object being tracked. The elevation difference channel produces a similar null in the elevation plane.

Another posibility, in addition to polarization diversity, is space diversity. Thus, two multi-polarized arrays can be spaced approximately 50 wavelengths apart, the horizontal elements of each quad going to a pair of separate receivers, and the vertical outputs to another pair. The output of these receivers can then go to a diversity combiner and thence to either the input of the system or a recorder. This system can afford optimum signal strength, regardless of the source polarization, and with an effective gain increase in the order of 12 dB.

Flat-Type Oil-Filled High-Voltage Cables

By J. S. MOLLERHOJ

From *Power Apparatus and Systems* (*A.I.E.E.*), U.S.A.
No. 54, June 1961,
pp. 326–332, 7 illustrations.

ELECTRICAL breakdown in high-voltage cables generally occurs when voids in the oil-impregnated paper insulation, formed by load cycles, are exposed to electrical discharge and ionization, with consequent heating and destruction of the insulation. One method of avoiding such ionization is to maintain complete freedom from voids under all service conditions. The alternative course is to keep the voids under sufficient pressure.

Among the various types of cables developed according to these principles and designed to replace ordinary solid-type cables for voltages of 30 kV and above, the conventional oil-filled cable, invented by Emanueli in 1920, appeared first. The latest of these types, the flat cable, made its appearance at the beginning of World War II.

Operation and Construction

In the flat-type cable, the oil-volume variations caused by the load cycles are compensated for by elastic deformations of the reinforced cable sheath. These deformations consist partly of a radial deflection of the resiliently reinforced flat sides and partly of a radial displacement of the same sides, the latter contribution arising from elastic deformation of the insulated cores, whereby the long axis of the cable cross-section decreases, while the short axis increases, and *vice versa*.

The three conductors lapped with semi-conducting carbonized paper, cellulose paper, carbonized paper, aluminium-, or copper-foil screen, are placed side by side. Next comes a flat sheath with a thin paper- and copper-tape lapping, followed by a resilient pressure device consisting of bronze tapes, corrugated laterally, but longitudinally applied and tightly bound to the flat sides by means of copper wires. A special anti-corrosive protection is applied over this resilient construction. This is followed by a wire armour for submarine cables, while both land and submarine cables have an overall serving of bituminized jute.

The flat cable utilizes joints and terminals of simple design, and no membranous tanks or other auxiliary equipment are used to govern the internal oil pressure, since the cable is completely self-compensating.

The Cable Dielectric

The paper insulation consists of high-grade cellulose paper. For 33- and 66-kV cables, a paper thickness of 0·004 in. is used, whereas at 132 kV and above, when the impulse strength becomes the deciding stress factor, the size is graduated according to the voltage.

The oil used is a naphthene-base oil with little gas development and safe gas absorption, and is particularly resistant to heat and ageing. The oil in the four channels of the flat cable does not move lengthwise to the same extent as in conventional oil-filled cables and does so

only to effect minor oil-volume compensations in joints or terminals, or along the cable itself, as a result of differing temperatures and levels along the route. Thus, an oil has been chosen with a viscosity of about 170 centistokes at 20°C, i.e., the oil, though fluid, is from four to five times more viscous than the oil used in conventional oil-filled cables. The reason for this is the increased stability of a more viscous oil and the adaptation of such an oil to an easy freezing process by means of carbondioxide ice, with a view to improving the installation of joints and terminals. The same oil is also used for the impregnation of the insulated conductors themselves. Alternatively, a still more viscous oil or compound can be applied.

The flat-type land cable is normally designed for an internal maximum pressure of 85 psi. During variations from no-load to full-load, i.e., with a conductor-temperature increase up to 70°C, the pressure increase amounts to between 28 and 36 psi, and a seasonal variation of 15°C in the temperature of the environment corresponds to a pressure variation of about 14 psi. Corresponding to a minimum pressure of 7 psi, the permissible height difference along a land-cable stretch would then normally be about 80 ft. For greater differences in level, it is necessary to apply stop joints of conventional design or an increased conductor size. As an alternative solution, a higher oil pressure and a correspondingly reinforced membrane construction for the lower cable duct can be used. For cables in flat districts, a maximum pressure of only 40 to 50 psi will provide an economic cable design.

In submarine cables, stop joints are unnecessary, owing to the external water pressure on the cable. Since the specific gravity of water is about 10% higher than that of the oil, the static pressure difference between the oil and water decreases by 1 psi for each 21·4 ft of water depth. At depths where the water pressure exceeds the oil pressure, a reinforcing bronze tape around the three insulated cores may be applied under the sheath.

The Cable Sheath

The membranous cable sheath is made of a lead alloy containing 0·2% tin and 0·075% cadmium. This alloy has for many years proved successful under vibration and against the large deformations occurring in cables installed in ships and in underground cable networks with manholes, etc., under unfavourable conditions, with strains up to 0·5% in an oxygenous atmosphere.

In the flat cable, the maximum possible sheath strain is 0·25% at a load variation from no-load to full-load, but in practice the cyclic strain is much smaller, depending on the load curves. A cyclic strain of 0·07 to 0·15% may generally be assumed, but, even at 0·25% cyclic strain, the flat cable sheath will stand 168,000 1-min cycles in degasified oil, or at least 118,000 3-min cycles. At 0·15% cyclic strain, the number of cycles will be higher. Assuming a factor of 3 as appropriate for relating a 3-min cycle to one daily cycle of several hours duration and 275 days per annum, the life of the sheath will exceed 143 years.

The Resilient Membrane

The core of the resilient membrane is a thin metal-tape lapping around a lead sheath, in order to secure a constant length of the lead-sheath periphery during the varying internal oil pressure in the cable. This lapping also supports the corrugated bronze tapes placed thereon and applied longitudinally, but with lateral corrugations. These tapes, consisting of 8% tin-bronze, are so designed that they can stand elastically the maximum deflections of the flat sides without causing any reduction in the flexibility of the cable, and at the same time use a minimum amount of bronze. The corrugated bronze tapes are bound tightly to the cable by copper wires of sufficient strength to withstand the maximum pressure of the cable.

The membrane is protected from corrosion by an external covering of material, such as thermoplastic tape or alternate layers of overlapping rubber tape and bitumen- and oil-impregnated crêpe papers. Finally, the cable is served with bituminized jute and adequately compounded.

Submarine-Cable Armour

For submarine-cable armouring, galvanized-steel wires or wires of aluminium are generally used, the aluminium being alloyed with, for instance, 2% magnesium and 0·25% manganese. The latter material is preferable for large cables, where a certain maximum weight should not be exceeded.

Manufacture

In its initial stages the manufacture of flat cable is the same as for other high-voltage cables. Oil impregnation after drying can be effected before or after lead sheathing, but experience has shown that impregnation before sheathing saves time and ensures a better dielectric with smaller losses. The corrugation of the bronze tapes in a separate corrugation unit is an easy process, and their application to the cable is also very simple by means of a small wire-binding attachment incorporated in the armouring machine. A noticeable deviation from other three-core cable manufacture is the omission of the laying-up process, thus permitting increased manufacturing lengths of flat cable.

With equal insulated conductor diameters, the minimum permissible bending radius for flat cables and single-core cables is the same. Consequently, the only condition for making flat cables of the same maximum manufacturing length as single-core cables is that the drum-stands at the lead press and the armouring machine can accommodate cable drums of the proper size.

Joints and Terminals

Common features of the joints and terminals are their great simplicity of design and the application of an oil freezer to the adjacent cable ends, to prevent oil from flowing out of the cables during the jointing process and also to permit an effective vacuum treatment at the subsequent drying and oil-filling of the joints. Such precautions naturally add to the safety in making joints with high breakdown strength. For freezing, use can be made of a box mounted on a cable end, with blocks of carbon-dioxide ice resting directly upon the upper corrugated bronze tapes, while similar blocks are held against the lower bronze tapes by a spring arrangement.

For submarine cables, the most important joint is the flexible type, which can stand drumming and paying-out together with the cable itself, and thus can be applied ashore to a number of manufacturing lengths for subsequent laying of the complete cable run in one operation. This type of joint is also the simplest for repair work at sea.

The sleeve consists of a flat corrugated tinned-copper tube with nipples at the ends for vacuum treatment and oil-filling, and wipe-soldered onto the lead sheaths. Short, flat copper rods are tightly bound over the two solderings, so that the solderings themselves are stiffened and can stand the drumming processes without breakage. The flat sleeve sides are covered with heavy corrugated bronze tapes tightly bound onto the tube sides to prevent membranous movements of the sleeve, but at the same time maintaining its flexibility.

The whole joint is armoured by winding the armouring wires of the two cable ends around and beyond the sleeve to a certain distance at each side. Each layer of armouring wires rests on a lapping of insulating tape or tarred-jute serving, and each armouring-wire layer is bound down by tight wire bindings at intervals of 30 in.

This procedure is the same as that known from the classic "overhaul splices" in deep-sea telegraph cables.

The terminal joint contains a splitter box in which the lead sheath is soldered, and from which the insulated conductors are led to the individual sealing ends through flanged copper tubes. Generally, the installation is made with the terminal and its steel structure in a horizontal position, and is then erected in the vertical position.

To control the minimum oil pressure, pressure-control alarm boxes are provided at the terminal and stop joints. The control box contains electrical contacts governed by the oil pressure, a pressure gauge, a pressure-control device, and a valve plus a nipple for oil-filling. On completion of the entire cable installation, the oil pressure is adjusted through this nipple. Normally, the oil pressure then requires no further attention.

Cable Laying

Cable laying is straightforward, both for land cables and for short submarine cables without joints. Submarine cables comprising a number of manufacturing lengths can be laid length by length and joined at sea but, generally, jointing ashore, with subsequent laying in one operation, is to be preferred. In most cases, with the flat cable the floating drum has been used for this purpose, although laying from coil in a ship's hold has also been practised.

As is well known from the paying-out of large drum lengths, there is a tendency for the inner end of the cable to move out gradually through the flange hole during laying. Any such difficulty is overcome by attaching the inner cable end to a turnable ring placed around the drum outside the drumming area, and in making arrangements to brake this turnable ring conveniently from the bridge.

The high degree of flexibility becomes apparent when the flat cable has to be laid in bights or coiled. Normally the cable lies on one of its flat sides but, when it passes around a bend, it gradually rotates through 90 deg. about its longitudinal axis as it approaches the bend and then rotates 90 deg. again as it leaves the bend. During coiling, the flat cable, like other cables, rotates through 360 deg. about its longitudinal axis for each coil winding or turn, and is especially suitable for oblong coiling, e.g., in railway trucks or rectangular ship holds where the cable "goes on edge" when taking the two narrow end bends of each turn, and rotates 180 deg. through each of the two long sides of the turn.

In the laying and operation of oil-filled cables, it is now an established fact that an oil leakage is not serious and that ample time is available to take appropriate measures. If a lead sheath is damaged, the oil will flow out, but the rate of flow will gradually diminish and will then cease when pressure equilibrium is established. This is true of both land and submarine cables. In submarine cables, cases may also occur of the water ultimately entering the cable; however, water penetration will be limited to a short cable section from the fault down to the first small dip in the contour of the sea bottom, where the corresponding cable bend will act as a water trap.

Three-Core and Single-Core Submarine Cables

For submarine-cable installations, the use of four single-core cables is sometimes recommended with a view to utilizing the fourth cable as a convenient spare in case one of the other three cables is damaged.

It should be kept in mind, however, that, when mechanically feasible, the application of two three-core cables, each designed for the full load, is a better alternative, since two such cables offer the same spare possibility and occupy less space on the sea bed. Also, the two cables operating in parallel, with accordingly reduced losses prove to be a more economical solution when the cable losses are capitalized in the two cases. This is particularly true when steel-wire armouring is used for the two cable types.

Conclusions

The special features of flat cable may be summarized as follows:—

(1) The flat cable provides fully oil-impregnated dielectric under all working conditions in a completely self-compensating cable with simple joints and terminals and no necessity for auxiliary equipment to maintain the positive internal oil pressure.

(2) The flat cable is a three-core cable with the same flexibility as that of single-core cables and of the same insulated conductor diameter, permitting the manufacture and laying of cables with larger core diameters for higher voltages than is possible with other types of three-core cables.

(3) As a three-core cable with no laying-up of the cores, it can be insulated, dried, and impregnated in the same maximum lengths as corresponding single-core cables, and even completed in such manufacturing lengths with suitable drumming equipment on the lead press and the armouring machine.

(4) The self-compensation throughout the entire cable length, with no, or very little, longitudinal oil flow in the oil channels of the cable, eliminates transient oil pressures due to sudden load changes. Furthermore, it permits the use of an oil of such viscosity that freezing with carbon-dioxide ice of the cable ends next to joints and terminals can be effected. As a result, installation work is simplified and improved, since drying and oil-filling can be accomplished during the vacuum treatment.

Although these features are useful in land cables, they offer particular advantages where long submarine cables are concerned. The three-core oil-filled self-compensating construction, together with long manufacturing lengths and great flexibility, should, in the latter case, be of great importance.

A New Type of Stop-Valve for High-Pressure Steam Lines

By C. SATTLER

From *Brennstoff-Wärme-Kraft*, Germany,
Vol. 13, No. 6, June 1961,
pp. 276–277, 3 illustrations.

CONVENTIONAL types of stop-valve, with wedge gates, parallel gates, etc., arranged transversely to the direction of flow, have given satisfactory service over a wide range of conditions in steam-engineering and hydraulic-engineering applications. However, increasing temperatures and pressures necessitate continuous improvements in closing systems. Service failures are particularly objectionable in modern high-pressure steam-generating plant, as they can cause stoppages of individual units or even of entire sections of the plant for fairly long periods.

At present, increasing importance is being assigned to the actuating forces and to the opening and closing times of valves used for the control of preheaters, extraction or change-over operations (e.g., in by-pass systems to preheaters, or in twin feedwater lines to parallel-connected preheater groups). Many plant operators are now asking for short closing times of about 5 to 6 sec, but these cannot be achieved with valves of conventional types. As an example of the reasons for such a requirement, it will be recalled that quick-closing valves in the lines between the turbine and the high-pressure preheaters are included in the hydraulic control circuit of the turbine, so that it can be shut off as soon as the level controllers indicate a critical level of condensate in the preheaters. Thus, in case of trouble with a preheater, the control valves must be capable of operating with minimum delay to avoid shutdowns of major units.

For this reason, a number of special designs of valves with hydraulically actuated pistons have been developed and have been installed in several recently built power stations. However, for various reasons, they cannot be regarded as a final solution to the problem. Following a new line of approach, a new design of valve has therefore been developed, which incorporates as basic features axial through-flow and closing members located in the path of the flow. These features have resulted in a compact design of very small external dimensions. The new valve, shown in Fig. 1, does not require additional space either for outward travel of the spindle during opening or for the accommodation of the closing devices. The moving internal components of the valve, which is suitable for rapid opening and closing and which can also be used for throttling, rotate about the flow axis only.

The housing *a* is made from a single forging. The rotary closing member, consisting of a rotor *b*, with a toothed segment *f* around the lower portion of its periphery and four rotatable closing vanes *e*, is located in the middle section of the flow discharge passages formed by guide-rings *c* (which have stationary vanes) on the inflow and outflow sides. The rotatable closing vanes *e*, of appreciable thickness, are inserted into recessed positions between the outer rim and hub of the rotor. The hub is rotatably mounted on a central pivot pin *d* which is supported by the inner guide-rings *c*. The worm-wheel segment *f* of the rotor rim is rotated by a worm *k* which is operated by means of a spindle *i*, a pair of spur gears (in a separate casing) with a reduction ratio of 4 : 1, and a handwheel. The guide-rings *c* have four sector-shaped passages *g* with axially curved contours acting as divergent/convergent nozzles, so as to provide a smooth flow pattern. The sealing surfaces *h* on the stationary vanes of the guide-rings *c* and on the movable vanes of the rotor *b* are faced with stellite.

In the open position (section *A* in Fig. 1), the four flow passages *g* provide a total flow area equal to that of the circular cross-sections at the two ends of the valve, and their axial contours are designed to provide a venturi-type distribution of velocity. During the closing process, the entire closing system is rotated through 45 deg. about the pipe axis. Each flow passage *g* is covered by a closing vane *e* (section *B* in Fig. 1), and pressure-dependent sealing is thus obtained. The clearances at the interfaces are solely those due to thermal expansion, so that no leakage losses can occur in the passages. The worm drive and the spindle *i* are situated outside the space occupied by the flow.

Only four turns of the spindle are required to close the valve from the open position (i.e., to rotate the closing system through 45 deg.). Consequently, with the 4 : 1 reduction gear, only 16 revolutions are required of the drive shaft, which can be driven by an electric motor.

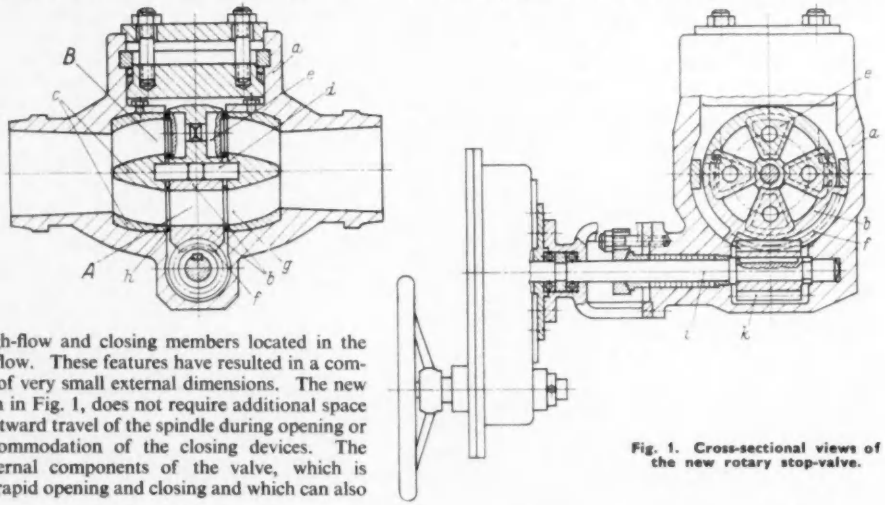

Fig. 1. Cross-sectional views of the new rotary stop-valve.

With a motor speed of 150 to 300 rpm, closing times of 3 to 6 sec can therefore be achieved without difficulty. Moreover, the driving torques are considerably lower than those required for valves of conventional types with the same flow diameter.

It should also be noted that all the movable internal parts can be inserted or removed through the top portion of the valve housing, which is closed by means of a self-sealing cover.

The advantages of this valve design include (1) quick actuating times (between 3 and 10 sec), (2) high reliability in service (the seals being fitted in positions which are protected from damage by foreign bodies), (3) no possibility of excessive pressures on the housing due to heating of entrapped water, (4) low flow resistances and extensive elimination of turbulent-flow losses, by suitable design of the steam-flow passages, and (5) very small external dimensions, with driving components not protruding appreciably from the housing.

A valve of this design has been subjected to tests in a steam line with a flow rate of 100 tons/hr at 120 atm and 530°C. During a period of 15 months the valve was opened and closed about 600 times, and inspection at the end of this period showed that the internal parts were in perfect condition. Only the spindle bearing required a minor improvement, and this was carried out after the first five months while the boiler was being inspected. The valve fulfilled all requirements as regards functioning and sealing without any trouble. The valve was also subjected to a flow control test, in order to assess its behaviour as a regulating valve. This test showed that it was possible to use it for flow regulation, and the noise levels at various openings were not different from those obtained with other regulating units.

The Motion of a Ball in a Ball Bearing

By F. HIRANO and H. TANOUE

From *Wear*, The Netherlands,
Vol. 4, No. 3, May/June 1961,
pp. 177-197, 22 illustrations.

THE motion of rolling elements in a rolling bearing deviates somewhat from ideal motion. Depending on operating conditions, slip and spinning motion take place. This deviation should have an important influence on the friction, wear, and life of rolling elements, so that an investigation into the motion of rolling elements is required for basic information on rolling bearings. The situation is simple in the case of a roller bearing, because observation of the motion is easy. Hampp[1] reported the results of measurement of the motion of rollers in a connecting-rod bearing by means of variable capacitance. Sasaki[2] recorded the locus of a point on the edge of a roller by using an optical method and analysed the slip of the roller.

In the case of ball bearings, on the other hand, balls have the freedom of three-dimensional motion, and observation of the motion becomes more difficult. One of the authors previously reported that a magnetized ball could successfully be used for tracing the motion of the ball[3]. Recently, the experiments have been resumed, and special attention has been given to the spinning motion of balls. The present paper, most of which has already been published in Japanese[4], deals mainly with the results obtained under a radial load. The case of thrust and combined load is now under investigation and will be reported later.

In order to study the motion of a ball in a ball bearing without disturbance, the change in flux due to the rolling motion of the magnetized ball has been observed, the bearing steel being sufficiently magnetic for this purpose. When the magnetized ball, inserted into a pocket of the cage, is rolling between the raceways, the magnetic poles also revolve. Consequently, the change in magnetic flux induces an alternating current in the circuit of a coil wound on an outer ring, the induced current being recorded on an oscillograph. The period of the current corresponds to the period of the rotation of the ball relative to the cage. Comparing the frequency of the actual change in flux with the ideal, the rate of slip is easily estimated. Moreover, the amplitude of the current is found to be at a maximum when the magnetic axis is perpendicular to the rolling axis. The current vanishes, however, when both axes coincide. Thus, the angle α between the rolling axis and the magnetic axis of the ball can be estimated from the fluctuations in amplitude.

Details of the four types of ball bearings used in this investigation are given in Table I, in which n_b is the speed of the ball relative to the cage [rpm], n_c is the speed of the cage or of the ball centre [rpm], $\omega_b{}^*$ is the theoretical angular velocity of the ball relative to the cage [radians/sec], and $\omega_c{}^*$ is the theoretical angular velocity of the cage or ball centre [radians/sec].

Most of the experiments were carried out under radial loads of 100 kg on the deep-grooved Type No. 6307 bearing with a solid-brass cage and a radial clearance of 22 microns. All bearings were lubricated, mainly with spindle oil at a rate of 10 cc/min. To assess the influence of lubricants on the motion of the ball, cylinder oil and grease were also used.

TABLE I: DETAILS OF BEARINGS TESTED

Type	I.D. [mm]	O.D. [mm]	Width [mm]	Cage	Balls: Number	Balls: Diameter [mm]	Diameter of Outer Raceway [mm]	Radial Clearance [microns]	$\frac{n_b}{n_c} = \frac{\omega_b{}^*}{\omega_c{}^*}$
No. 6307	35	80	21	solid brass	8	13·5	71·50	22	5·30
No. 6307	35	80	21	pressed steel	8	13·5	71·50	22	5·30
No. 7307	35	80	21	solid brass	11	13·5	71·10	—	5·27
No. 7307	35	80	21	cageless	13	13·5	71·10	—	5·27
No. 6306	30	72	19	pressed steel	8	12·3	64·38	20	5·24
No. 6208	40	80	18	pressed steel	9	11·9	71·90	10	6·10

To obtain a change in flux sufficiently strong to be recorded on oscillograms, it was found necessary to give the ball a residual magnetism of about 200 gauss by means of a suitable magnetizing coil. It should be noted that the residual magnetism was found to decrease from its initial value during operation of the bearing. Calibrating experiments showed that the decrease ceased after 50,000 revolutions of the inner ring and that the final value of residual magnetism was 140 gauss, i.e., 70% of the initial value under radial loads above 100 kg. Consequently, in order to obtain reliable results, such experiments must be carried out after running at least 50,000 revolutions.

Owing to the freedom of three-dimensional motion of the ball, the position of its rolling axis relative to the magnetic axis can change with time. It is therefore necessary to determine the angle α between the axes from oscillograms, and for this purpose a preliminary experiment was carried out, in which balls of bearing type No. 6307, with definite angles α of 0°, 22·5°, 45°, 67·5°, and 90°, were prepared. The rolling axis was formed by short wires soldered to the ball and inserted into small holes drilled through the cage. Thus, the motion of the ball was constrained, and it behaved like a roller in a roller bearing. Oscillograms of maximum flux change corresponding to a value of α of 90° showed slight fluctuations in the amplitude A of the oscillogram, caused by the slip of the ball at the unloaded side, the period of fluctuation coinciding with that of the rotation of the cage. In the case of $\alpha = 0°$, however, the flux change was found to be negligibly small and, for all other bearings, measurements were carried out with a value of α of 90° only. It was also found that the amplitude A of the oscillogram was proportional to sin α at a constant shaft speed N, and calibration curves of $A/\sin\alpha$ as a function of shaft speed N were plotted for all bearings.

The oscillograms shown in Fig. 1 are examples of records taken under a radial load of 100 kg, Fig. 1a referring to a Type No. 6307 bearing operating at a shaft speed N of 1290 rpm, and Fig. 1b to a Type No. 7307 bearing operating at a shaft speed of 750 rpm. In these oscillograms, T is the period of revolution of the inner ring or shaft; Tb_b is the period of the rolling ball, with a maximum period $T_{b\,max}$; T_c is the period of one revolution of the cage or ball centre; and T_s is the period of fluctuation of the amplitude.

The short period T_b represents one revolution of the ball relative to the cage, and it should be appreciated that the oscillograms do not indicate an absolute motion of the ball, but the relative motion to the cage, because motion of the ball fixed to the cage does not induce any change in flux. The ball centre travels around the inner ring at a period T_c, and fluctuation of the amplitude A with T_c is caused by the slip of the ball at the unloaded side of the bearing. In Fig. 1b, an extremely large slip, represented by the prolonged period $T_{b\,max}$, is produced at the unloaded side, owing to the absence of a thrust load. At the loaded side, however, the period T_b coincides with the theoretical value.

In the oscillogram in Fig. 1a, the fluctuation with the long period T_s is remarkable. The amplitudes A_{max} and A_{min} correspond to the maximum and minimum values of the angle α between the magnetic and rolling axes of the ball. The change $\triangle\alpha = \alpha_{max} - \alpha_{min}$ in the momentary axis of rolling can be calculated by means of the calibration curves of $A/\sin\alpha$ as a function of N, mentioned above.

With all types of bearings, it was noted that the

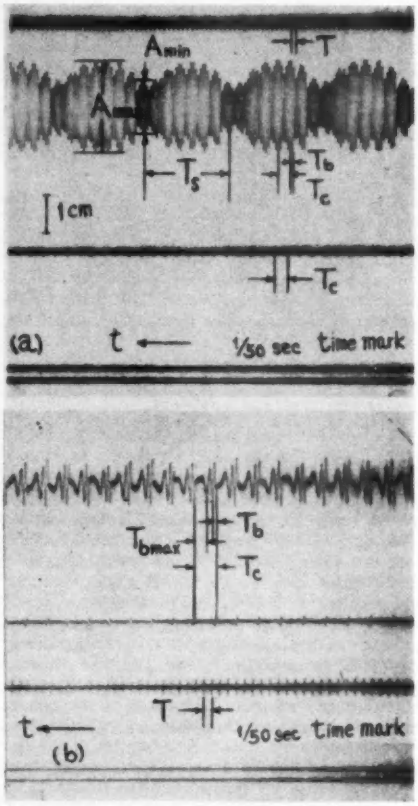

Fig. 1. Typical oscillograms of tests on ball bearings under a load of 100 kg, (a) for a Type No. 6307 bearing with a shaft speed N of 1290 rpm, and (b) for a Type No. 7307 bearing (N = 750 rpm).

oscillograms showed that considerable slip occurred at low speeds and that the slip decreased with increasing speed. The regular fluctuation in the value of the angle α was clearly shown in several records. Fig. 2 shows oscillograms of the results obtained under loads of 100 kg using bearings of Types No. 6306 and 6208 at different speeds, lubricated with spindle oil at a rate of 10 cc/min.

Slip of the Ball

Insofar as the motion of a ball in a ball bearing under a load P is concerned (Fig. 3), the ideal motion of the rolling elements can be expressed as

$$R_2\theta = R_1(\Theta - \theta) = r\varphi \quad .. \quad .. \quad .. \quad (1)$$

where r is the radius of the ball.

Consequently,

$$\theta/\Theta = \omega_c^*/\omega = R_1/(R_1 + R_2)$$
$$\text{and } \varphi/\theta = \omega_b^*/\omega_c^* = R_2/r \quad .. \quad .. \quad (2)$$

The values of ω_b^*/ω_c^* are listed in Table I. The actual angular velocities ω_b and ω_c measured on the oscillogram deviate from the theoretical values ω_b^* and ω_c^*. The value of ω_b fluctuates with the period T_c shown in Fig. 1. However, the actual angular velocity ω_c has been found in this investigation to coincide with the theoretical

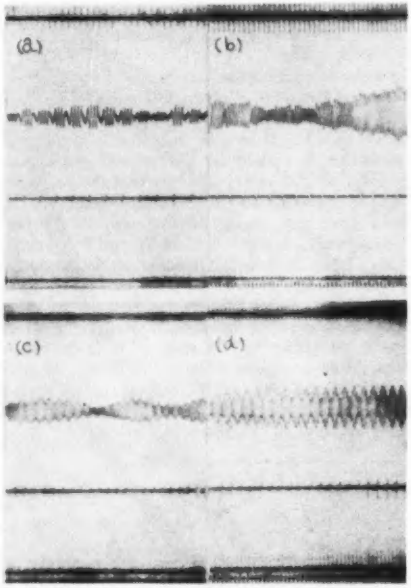

Fig. 2. Oscillograms of tests on ball bearings with pressed-steel cages under a load of 100 kg, lubricated with spindle oil at a rate of 10 cc/min, (a) for a Type No. 6306 bearing with a shaft speed N of 500 rpm, (b) for a Type No. 6306 bearing (N = 3000 rpm), (c) for a Type No. 6208 bearing (N = 1200 rpm), and (d) for a Type No. 6208 bearing (N = 3000 rpm).

angular velocity ω_c^*. In other words, there is no slip in the cage.

The mean value of $\omega_b/\omega_c = \omega_b/\omega_c^*$ is easily obtained by counting the number of waves included in a definite number of revolutions of the cage. The mean slip S is then given by the definition

$$S = (\omega_b^* - \omega_b)\omega_b^* = [(\omega_b^*/\omega_c^*) - (\omega_b/\omega_c)]\,/(\omega_b^*/\omega_c^*) \quad . . \qquad (3)$$

The maximum slip corresponding to $\omega_b = 2\pi/T_{b\,\max}$ is also significant. An estimate is impossible, however, without an appreciable error, so that only the mean slip S is considered in the following discussion.

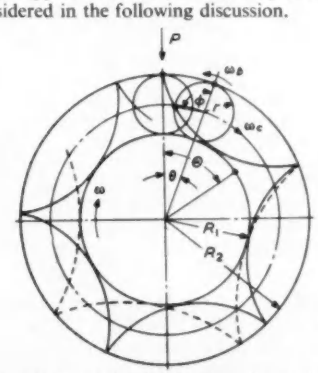

Fig. 3. Motion of a ball in a ball bearing, showing ideal motion (solid lines), and slip (dotted lines).

Insofar as the Type No. 6307 bearing is concerned, it was found that the mean slip S decreased with an increase in shaft speed N, maximum values of mean slip ranging from about 25% at 300 rpm to nearly zero at 5000 rpm. Slip also decreased with an increase in radial load. The effect of lubricant viscosity was rather small, but slip tended to decrease with increasing oil feed rates. With grease lubrication, a much lower degree of slip was observed.

Expressing the position of the ball centre by the angle measured from the position of the load applied in the direction of shaft rotation, it has been found[5] that slip is initiated at nearly 90°, gradually developing at the unloaded side, attaining a maximum at from 290 to 300°, and abruptly disappearing at from 320 to 330°. The actual clearance between the ball and raceways increases at the unloaded side, owing to the application of a radial load. Consequently, the contact of the ball with the inner race becomes loose, causing slip of the ball. However, under pure thrust load, the ball always keeps contact with the raceways, and slip does not occur, even at low speeds.

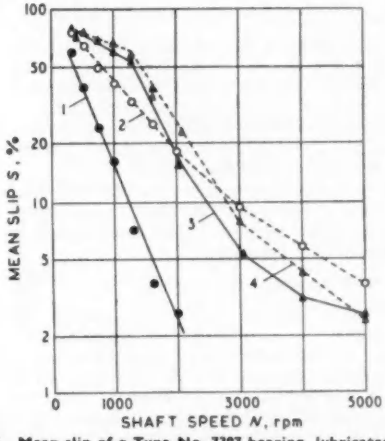

Fig. 4. Mean slip of a Type No. 7307 bearing, lubricated with spindle oil at a rate of 10 cc/min, as a function of shaft speed N, under different conditions of load P.
(1) Solid-cage bearing, P = 100 kg.
(2) Solid-cage bearing, P = 0.
(3) Cageless bearing, P = 100 kg.
(4) Cageless bearing, P = 0.

It is therefore considered that radial clearance has a marked influence on slip. Accordingly, tests were carried out on the Type No. 6307 bearing, using slightly smaller balls in place of the normal balls, and thereby increasing the radial clearance to 60 microns, as compared with the normal value of 22 microns. The results of these tests showed that slip increased considerably, except in the case of no-load conditions at the higher speeds. When the normal magnetized ball was replaced by a slightly smaller ball, slip was found to increase still more. It is reasonable to consider that the clearance between the magnetized ball and the raceway was increased because the neighbouring balls were of normal size. There was no significant difference in the results obtained with the Type No. 6307 bearing with a solid-brass cage or a pressed-steel cage.

The results of tests on the angular contact bearing Type No. 7307 under no-load conditions and under a load of 100 kg are shown in Fig. 4. Though this type of bearing should be operated under a thrust load, the tests were carried out under pure radial load. Consequently, the contact between the balls and the raceways

became much looser, compared with the deep-grooved Type No. 6307 bearing, leading to a remarkable increase in mean slip, even at the higher speeds. The cageless Type No. 7307 bearing was prepared by removing the cage and substituting 13 balls in place of the 11 balls normally used. The results of tests with this cageless bearing are also included in Fig. 4, the extraordinarily high value of slip noted being attributed to the braking action produced by adjacent balls.

In the case of the Type No. 6306 bearing, the values of mean slip ranged from about 40% at a shaft speed of 300 rpm to nearly zero at 5000 rpm. The mean slip of the Type No. 6208 bearing did not exceed 3%, except at very low speeds. These two bearings were provided with pressed-steel cages and, since deformation of the cages after repeated mounting and dismounting was inevitable, the reproducibility of data was inferior, compared with those for solid-cage bearings.

Changes in the Rolling Axis of the Ball

The fluctuation of amplitude with the period T_s shown in Fig. 1 tends to maintain its wave-form for a long time or after a repeated increase and decrease in shaft speed. Furthermore, it has been verified that the behaviour of each ball is exactly the same, except for its phase, and the resulting current induced by the magnetized balls has a regular form.

If n_s is the frequency of the fluctuation [cpm] or $\omega_s = 2\pi/T_s$ [radians/sec], the ratio ω_s/ω_c is equal to the difference of ω_b/ω_c from the nearest integer m, and the relation can be expressed as

$$\omega_s/\omega_c = |(\omega_b/\omega_c) - m| \text{ or } n_s/n_c = |(n_b/n_c) - m| \quad (4)$$

where $n_b = 2\pi\omega_b/60$, and $n_c = 2\pi\omega_c/60$. Because $\omega_b^*/\omega_c^* = 5{\cdot}30$ in the case of the Type No. 6307 bearing, as indicated in Table I, the value of m is 5, with a few exceptions where $m = 4$. In the case of the No. 7307 bearing, however, where considerable slip is observed, values of m of 2, 3, and 4 frequently appear, in addition to $m = 5$. This means that the period T_s is determined by the number of revolutions until the accumulation of the phase lag of the motion of the ball becomes 2π.

Since the fluctuation of the amplitude represents the change in the angle α between the rolling axis and the magnetic axis, the frequency ω_s or n_s is that of the fluctuation of the instantaneous rolling axis relative to the ball. If this change in angle α is designated $\triangle\alpha$ and is plotted as a function of shaft speed N, the resulting curves show resonance. The dependence of $\triangle\alpha$ on speed is not unique, and the relation becomes different if slip varies as a result of load changes or other factors. The proportionality constant, i.e., $\triangle\alpha \sin(\pi\omega_s/\omega_c)$, increases with slip.

Since, at the beginning, the position A of the ball in Fig. 5 is considered to be constant under given operating conditions, the displacement of a point C_0 on the surface of the ball, e.g., the displacement of the magnetic pole after each revolution of the ball centre, can be treated as follows:—

If the ball behaves as a roller in a roller bearing, the point C_0 makes ω_b/ω_c revolutions about the x-axis at the end of one revolution of the ball centre and comes to the point C_0'. The phase shift β [radians] is then expressed by

$$\beta = 2\pi\{(\omega_b/\omega_c) - m\} \quad \text{or} \quad |\beta| = 2\pi\omega_s/\omega_c \quad (5)$$

After successive revolutions of the ball centre, the point travels to C_0'', C_0''', . . . Because angle C_0Ox = angle $C_0'Ox = \ldots = \alpha$ in this case, fluctuation of the amplitude does not occur.

In order to explain the fluctuation of the amplitude, a deviation of the point C_0 from the path $C_0'C_0''C_0''' \ldots$ should be assumed. Let the position of C_0 after the deviation be C_1'. It may be reasonable to assume that the deviation is caused by the angular displacement ε about the diameter AB (y-axis) passing the contact point A. At the unloaded side, the ball is set free from contact with the inner race, though contact with the outer race is still maintained, owing to the centrifugal force acting on the ball. Thus, the effect of the cage on the motion of the ball becomes significant at the unloaded side. Actually, there is always more or less deviation from the ideal contact condition. Especially, the contact point of the ball with the pocket of the cage or with the groove of the outer race may have a slight offset from the plane of symmetry of the groove. The offset causes a spinning moment about the axis AB. This suggests the origin of the displacement ε, i.e., the spin.

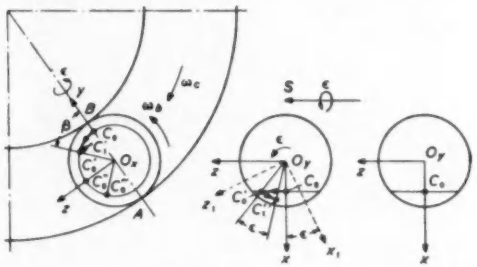

Fig. 5. Displacement of the magnetic pole as a result of slip

The change in the rolling axis of the ball is explained by assuming the existence of spin associated with slip. In order to find the factors affecting it, spin must first be calculated by substituting the observed data of (ω_b/ω_c) or (ω_s/ω_c) and $\triangle\alpha$ in the theoretical relation

$$\sin(\triangle\alpha/2) = \sin(\varepsilon/2)/\sin(\pi\omega_s/\omega_c) = \sin(\varepsilon/2)/|\sin(\pi\omega_b/\omega_c)| \quad \ldots \quad \ldots \quad (6)$$

When the results are plotted as a function of the mean slip S, it is confirmed that spin ε is proportional to slip S.

It should be noted, however, that the proportionality constant, i.e., $\triangle\alpha \sin(\pi\omega_s/\omega_c)$ is found to depend on the type of bearing and on the operating conditions. Since spin probably originates in the asymmetrical contact of the ball with the pocket of the cage or with the groove of the outer ring, tests were carried out, exaggerating this effect. One of the pockets was offset in the axial direction of the bearing, the amount of offset being 0·3 mm in the extreme case and 0·15 mm in the moderate case. The position of the pocket or hole into which the magnetized

(*Concluded on page 155*)

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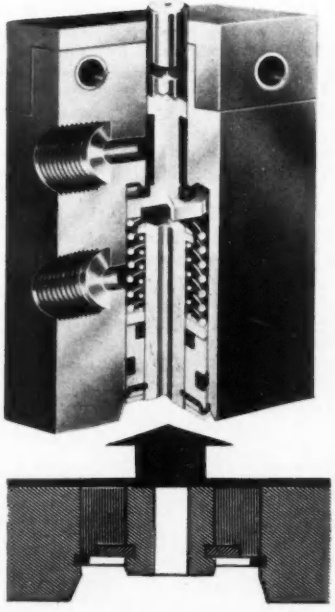

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7th EUROPEAN MACHINE TOOL EXHIBITION

Organized under the auspices of the European Committee for Co-operation of the Machine-Tool Industries, the 7th European Machine-Tool Exhibition will take place in the Palais du Centenaire, Brussels, between September 3 and 12, 1961. As is only to be expected from these highly successful exhibitions, the first six of which were held respectively in Paris (1951), Hanover (1952), Brussels (1953), Milan (1954), Hanover (1957), and Paris (1959), this latest exhibition will feature the products of practically all leading manufacturers of machine tools and equipment throughout Europe, including small tools, accessories, attachments and instruments, as well as metalworking and other machine tools. In addition, in the floor space of over 450,000 sq ft, a wide range of instruments and apparatus for measuring, controlling, and checking, together with testing machines, welding equipment, metal- or plastic-moulding machines, and equipment for heat treatment or surface treatment connected with the machining of metals, will be featured. The 4000 machines exhibited will represent the products of 762 manufacturers, of which 280 are German, 145 are French, 91 are Swiss, 87 are Italian, 65 are British, 38 are Belgian, 21 are Dutch, 17 are Swedish, 13 are Austrian, and 5 are Danish. A preview of some of these machines is given in the following pages.

The Churchill Machine Tool Co. Ltd.

Of the range of machines to be exhibited by The Churchill Machine Tool Co. Ltd., of Broadheath, Manchester, two are of special interest in that they demonstrate the contribution these machines can make in the field of automatic and semi-automatic manufacture, using unskilled labour.

One of these machines is the Churchill Model "BW" fully automatic plain cylindrical grinding machine with automatic loading (Fig. 1). In addition to automatic loading of the components, this machine has a completely controlled operation cycle which provides for automatic grinding of the component, gauging to size, and automatic ejection. Provision is also made for automatic wheel-truing and compensation for wheel wear. One of the special features of this machine is the patented Churchill diminishing feed, which simulates the skill of the operator in that feed is automatically and progressively reduced as size is reached on the workpiece. The grinding forces are thus reduced as size is approached, ensuring that the finished workpiece is geometrically, as well as dimensionally, correct. Repeat size within close limits is achieved by a system of "two-stage" control of the feeding cycle, the change from the roughing stage to the finishing stage being related to the final size.

The machine is so arranged that, after setting up the first component for grinding to size and after having decided the number which can be ground at one wheel truing, the loading, grinding, wheel-truing and compensation, and unloading cycles are carried out entirely automatically. Control of the machine cycle is effected by an electro-pneumatic sizing gauge through signals given to electro-hydraulic and electro-mechanical mechanisms to effect rotational movement of the workpiece and traverse, as well as the feeding movements of the grinding wheel and diamond.

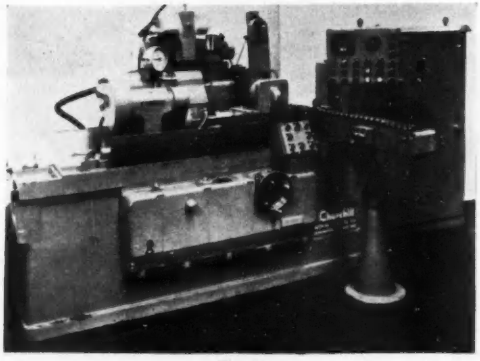
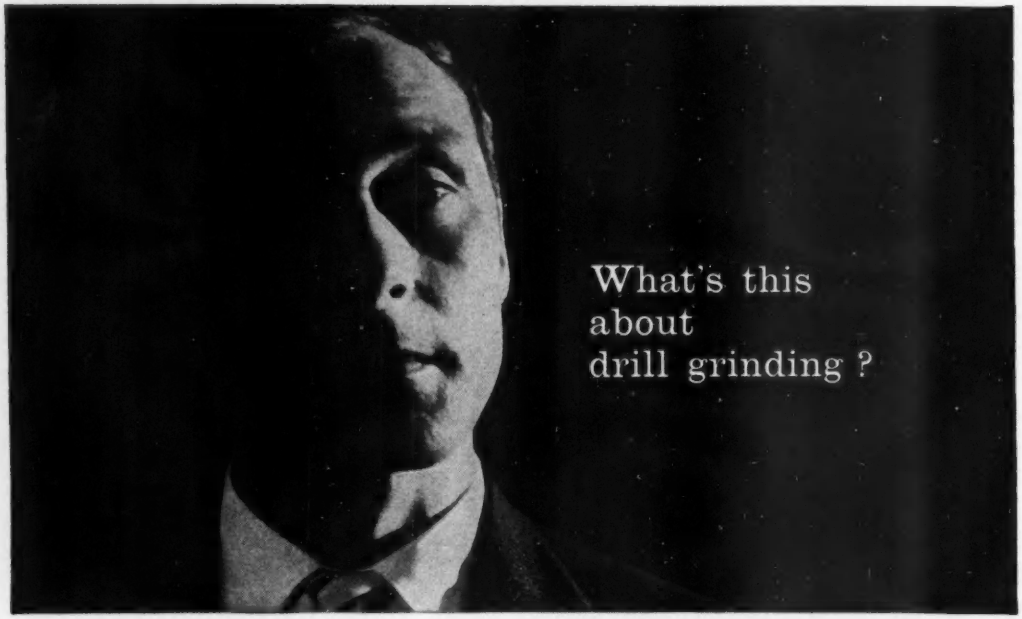


Fig. 1.

Different types of loading devices can be fitted to this machine. One, shown fitted to the machine in Fig. 1, is known as the swinging-arm loader and can be applied particularly to the machine when it is used in a link-line system of machine arrangement. It can, however, also be used in conjunction with an articulated or gravity-type magazine in a grouped system of machine arrangement.

The second machine is the Churchill Model "HBM" fully automatic internal and face-grinding machine. In this machine (Fig. 2) grinding and sizing of both the bore and external face are within the automatic cycle. The machine can also be arranged for diamond sizing or plug-gauge sizing to suit the component being ground. When the number of components is insufficient to warrant large batch production, the automatic cycle of operations can be rendered inoperative, enabling an operator to use the machine as a plain internal grinder for one-off production or very small quantities. A special time-saving device is a feed accelerator, by means of which the feed motor runs at its highest speed until contact is established between the grinding wheel and the bore. Where stock allowance varies, useful time is thus saved on components having the smallest amount of stock, as the wheel "skips" over spaces until actual contact is made with the metal.

This latest Model "HBM" machine is fitted with a new automatic facing device, with which an external face is ground square with the bore of the component, both operations being carried out automatically. Provision is made for vertical adjustment of the wheelhead to permit the face grinding wheel to be correctly positioned, so that the face area is effectively covered in the grinding operation. The truing diamond is arranged in such a way that the facing wheel is dressed with a relief to reduce the contact area with the work and to provide a cutting edge. It should also be noted that the final stage has now been reached in the complete automation of the



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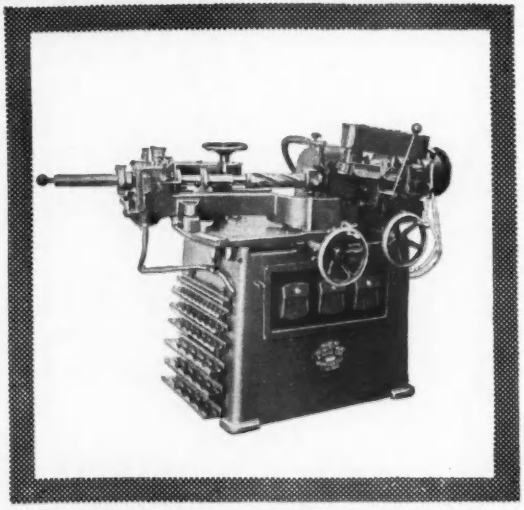

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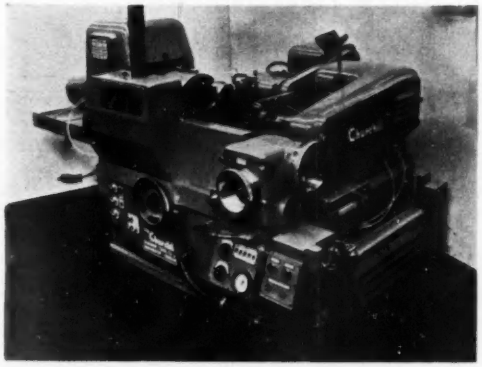

Fig. 2.

machine for bore grinding or for combined bore and face grinding by the addition of an automatic work-loading device, specially designed for this particular machine. The device consists of two brackets mounted on the front apron box of the machine and spaced apart to carry guide-bars on which a carriage slides. A swinging arm carrying the workpiece can swing from the loading chute or conveyor to the chuck of the machines and is mounted, together with its actuating mechanism, on the carriage. All movements of the carriage and swinging arm are controlled in proper sequence by means of a pneumatic circuit and its incorporated valves.

H. W. Ward & Co. Ltd.

Exhibits from H. W. Ward & Co. Ltd., of Birmingham, will include three capstan lathes and two combination turret lathes, each tooled up to show its versatility. Of the capstan lathes, all of which embody the new Ward double-slide capstan, the smallest is the Model 2 D.S. lathe, which has a standard bar capacity of 1¼ in., though the machine shown will have an oversize bar capacity of 1½ in. The second capstan lathe is the Model 3 D.S., which has a normal bar capacity of 1½ in., while the largest will be the Model 7 D.S. capstan lathe, which has a standard spindle capacity of 2 in. With this machine, the rigidity of a combination turret lathe is achieved within the limit of the capstan working stroke.

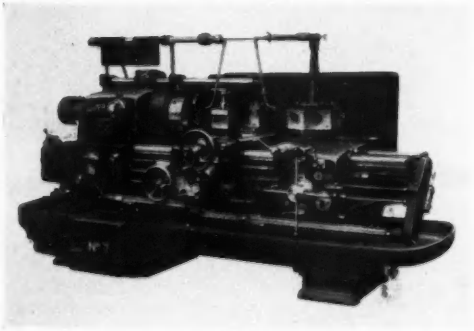

Fig. 3.

The largest machine to be exhibited by Ward is their No. 10/13 combination turret lathe, which has a spindle bore of 5¼ in. and a swing over the bed of 29 in. For the first time, a Ward lathe of this size will be used to demonstrate hydraulic copy-turning. The second combination turret lathe is the Model No. 7 "Preselector", shown in Fig. 3. This machine has an exactly equivalent capacity to the well-known Ward No. 7 combination turret lathe, and is fitted with dial selection of spindle speeds and direction of rotation, combined with a single-lever arrangement of the selected speed. This machine will be used to demonstrate external copy-turning with drilling and boring operations at the same time. Both roughing and finishing operations will be shown.

David Brown Industries Ltd.

In addition to their No. 10 "Hydrax" high-production gear-hobbing machine with automatic conveyor loading, and their No. S.12.H. production gear-shaving machine with automatic conveyor loading, the David Brown Machine-Tool Division, Manchester, will be featuring their UPH.30 ultra-precision gear-hobbing machine with electronic accuracy control. This machine, which has been designed to meet the increasing demand for a precision gear hobber of about 30-in. capacity, incorporates electronic control equipment for checking and automatically correcting any errors in the table drive. The cutting cycle is fully automatic and is controlled by a single push-button. The cradle, over-arm support, and steady-bracket are hydraulically clamped. Although primarily intended for the fully automatic cutting of spur and helical gears, the machine can, if required, be supplied for manual operation without the automatic cutting cycle. In this form, the machine is eminently suitable for generating small batches of spur and helical gears, sprockets, and spline shafts. An optional universal hob slide can be fitted, enabling wormwheels to be generated by the tangential-feed method.

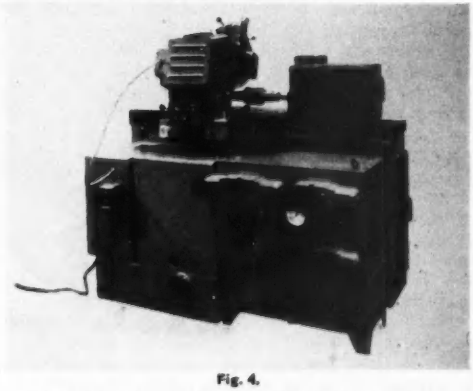

Fig. 4.

Also to be exhibited is a new addition to their range of products, the No. 6 hob sharpener. This machine (Fig. 4) will accommodate hobs up to 6 in. in diameter and 12 in. in length, and this capacity can be utilized to sharpen, say, three 4-in. hobs in one mounting—a unique feature, compared with any other machine. The machine is extremely simple to set and operate, and unit construction has been adopted to assist maintenance routine. Table speeds, up to 25 fpm, are variable hydraulically, and a stroke up to a maximum of 17 in. can be applied.

Any hob from 4 to 36 gashes can be sharpened on this machine, the setting for lead of gash being obtained by an easily accessible sine-bar device. Setting is calibrated to 1 minute. Accurate hydraulic indexing is provided, and an interlock prevents table movement until indexing

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MODEL "OG 45" HORIZONTAL COLD CHAMBER

is complete. It is possible to grind in either direction, with feeds down to a minimum of 0·0005 in. A trimmer unit provides for radial and non-radial sharpening, and all working slides are fully enclosed for protection.

In addition to a selection of David Brown measuring instruments and cutting tools, their No. 18 involute and helix measuring machine will also be exhibited. This machine covers the intermediate sizes of spur and helical gears with base-circle diameters ranging from $\frac{7}{8}$ to 18 in., deviations from the theoretical involute tooth profile being easily checked and recorded on graph paper.

The Sheffield Twist Drill & Steel Co. Ltd.

Out of a wide range of Dormer equipment, to be exhibited by The Sheffield Twist Drill & Steel Co. Ltd., of Sheffield 11, including drills, reamers, milling cutters, screwed-shank tools, and machine vices, drill-sharpening machines, and point-thinning machines, special interest attaches to the Dormer profile tool and cutter grinder, which is a versatile machine fulfilling the functions of a conventional tool and cutter grinder, a form grinder, a radius grinder, and a gashing machine.

Fig. 5.

Quite apart from its radical departure from existing methods and techniques in the continuous form grinding of complex cutter profiles, the machine (Fig. 5) can carry out all the functions of a conventional universal tool and cutter grinder and can be operated for routine work in the ordinary way, without any need for dismantling, removing, or special adjusting of the machine or its parts. Insofar as form grinding is concerned, this hitherto complicated operation is achieved on the Dormer machine by the simple radial movement of one hand-lever. The combination of this action and the biased linear movement of the main slide maintains contact between the template and the master peg, automatically reproducing the required profile.

Profiles combining angles and radii on rotary multi-flute cutting tools can be form-ground, either to vernier settings or by template, on the periphery or end teeth. In addition, tools of flat or circular form can be form-ground by template or machine settings, while complex shapes can be plunge-ground with the wheel dressed by a diamond to the vernier settings. In addition to resharpening tools and cutters by face-grinding and regashing chip clearances, the machine can also be used to grind carbide tools with a suitable wheel, to generate spirals by means of a sine-bar attachment, and to carry out cylindrical grinding, using a motorized headstock.

W. E. Sykes, Ltd.

In addition to a wide range of equipment, including their VS8A semi-automatic shaving machine, their V10B vertical gear generator, and their V10B "Sykomatic", W. E. Sykes Ltd., of Staines, Middlesex, will be showing their Model 1B horizontal multi-cutter gear generator. This new model (Fig. 6), while still retaining the versatility of the company's double-headed horizontal machines, incorporates several new features to increase productivity and to simplify setting. Also, the built-in hydraulic power unit and hydraulic infeed provide facilities for either semi-automatic or fully automatic operation for large-volume production.

To provide increased capacity for long shaft gears, the work-spindle assembly, mounted on a sub-slide of the saddle, can be adjusted for a distance of 5 in. This feature, together with an increased diameter of work-spindle bore, allows considerably longer components to be accepted without in any way impairing the rigidity of the machine on more conventional applications. Switch-selected hydraulic infeed in one, two, or three cuts provides an accurate and constant rate of infeed which is completely independent of the component diameter. The infeed unit is controlled by a precision hydraulic device which gives a constant, preset incremental feed, irrespective of any change in oil viscosity due to temperature fluctuations. Rapid approach and withdrawal of the saddle are sequenced into the automatic infeed cycle, and setting for the desired infeed is simply accomplished by individually adjustable setting screws. The final cut position of the saddle is controlled by the hydraulically locked saddle reaching an adjustable dead-stop. The centre distance between the cutter spindles and the work spindle is indicated directly (to 0.001 in.) on an indicator showing the exact dimension in easily read separate numerals.

To obtain accurate control of the final cut rotation, the machine employs an electrical dial controller synchronized to the work-spindle index worm. An adjustable knob on the dial controller allows the final cut to be set either more or less than 360 deg., as required. This facility permits preliminary setting-up to be accomplished faster since, for example, the settings for a three-cut cycle can be checked in about 120 deg. of work rotation. The adjustable work-rotation controller is also used for segment gear cutting of any desired angle, a manually operated feed-reverse lever allowing cutting in either direction and thus avoiding unnecessary delay in resetting at the completion of each cycle. Control switches and a special sizing button allow a further saving of time when checking the final size of the component. When the trial cut is completed, the gear is checked for size; after making any corrections necessary the sizing button is depressed to feed the component directly into the finished depth.

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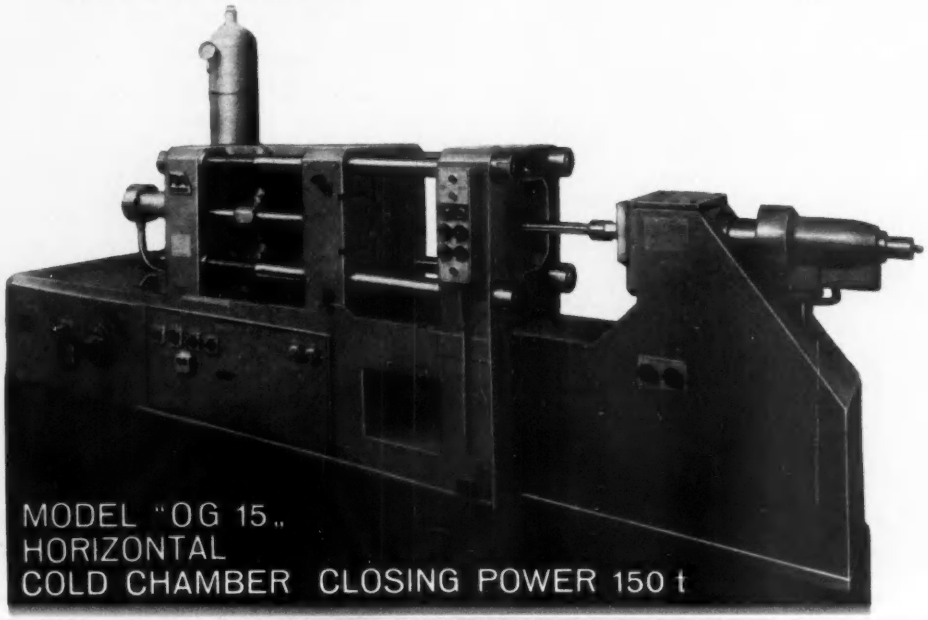

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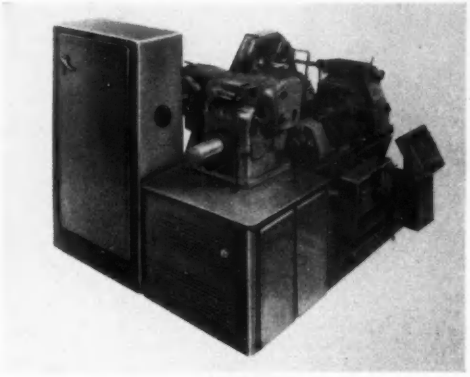

Fig. 6.

The standard model is supplied with a manually operated tailstock, with hydraulic operation available as extra equipment. Individually designed hydraulic clamping equipment is available for a wide range of components and, in these cases, tailstock operation, work clamping, cutting cycle, and unclamping are performed in an automatic sequenced cycle. Work location can be further assisted by the provision of loading rails or locators which relieve the operator of all attention other than placing the component in position and removing at the end of the operation. The semi-automatic models can also, in suitable cases, be supplied with magazine feeding arrangements for fully automatic continuous operation. In this type of machine, the cycle repeats continuously as long as the supply of blanks is maintained to the magazine.

Provision of a cluster attachment allows the machine to cut simultaneously two gears of differing numbers of teeth or helix angles; alternatively, one gear can be of spur form, whilst the second is helical. This facility is extremely valuable for the large-volume production of cluster gears, since such components are usually suitable for both hydraulic work clamping and magazine feed.

Lidköpings Mekaniska Verkstads A.B.

Among other equipment, Lidköpings Mekaniska Verkstads A.B., of Lidköping, Sweden, will be exhibiting their No. 2B/SP small precision centreless grinding machine, which is fitted with ultra-high-precision forward and back feed mechanisms for the grinding wheel. The positions of the wheel can be controlled by a push-button

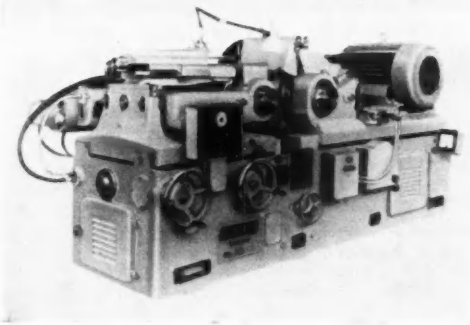

Fig. 7.

in both directions to an accuracy of 0·00002 in. This machine, which is the prototype of the No. 2C grinder, scheduled for delivery in 1962, will be shown in action through-feed grinding small cylindrical precision pins.

Another Lidköpings exhibit will be their No. 5B heavy-duty centreless grinding machine (Fig. 7). This machine will be set up for the continuous through-feed grinding of heavy steel bars, about 5 in. in diameter. The grinder mounts a 26-in. wheel, powered by a 85-hp motor, and is designed for taking components up to 13 in. in diameter. As a result of its extremely robust design and high power, it is stated that the grinding capacity of this machine is far superior to that of any other centreless grinder so far available. Furthermore, it is not only capable of removing large amounts of stock at high through-feed rates, but it will also produce work of exceptional accuracy and surface finish.

Salomé Frères

The "Synchromat" programme-controlled automatic multi-tool and copying lathe exhibited by Salomé Frères, of Nanterre (Seine), (sole British agents, **Dorman Machinery Sales Ltd.**, of Chalfont St. Peter, Bucks.) has been specifically designed to provide simplicity and flexibility of preselected automatic cycles for the economical solution of a number of machining problems in small, medium, and large production series. In addition to accurate copy-turning and boring operations, the lathe (Fig. 8) can be arranged for straight turning, drilling, boring, forming and facing operations, outstanding features of the machine being the modular design of precision transverse- and copying-slide units (which can be arranged to suit customers' requirements), and the simple and rapid plug-board type of setting for automatic programme control.

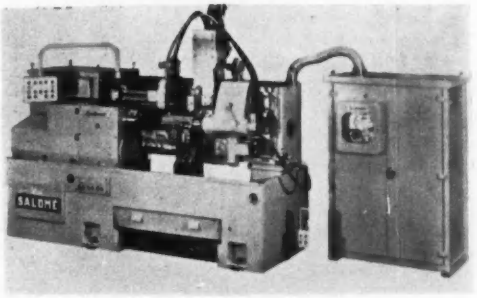

Fig. 8.

The interchangeable transverse-slide units are designed for fitting on both the upper and lower carriage slides. Two transverse slides can be fitted on each carriage slide. Alternatively, a copying slide can be fitted on the upper slide in combination with a transverse-slide unit arranged either to the left or right, thus providing an arrangement of one copying slide and three transverse slides. Three types of copying-slide units are available, i.e., single-pass, two-pass, and multi-pass, the latter providing for four fully automatic cylindrical roughing cuts and two profiling cuts from a master template. The patented copying system used provides constant linear feed on all profiles. The feeds of the slides remain constant, regardless of the cutting loads. All the automatic rapid- and fine-feed motions of the carriages, transverse units, and copying unit, together with chucking and tailstock operations, are hydraulically operated and controlled by

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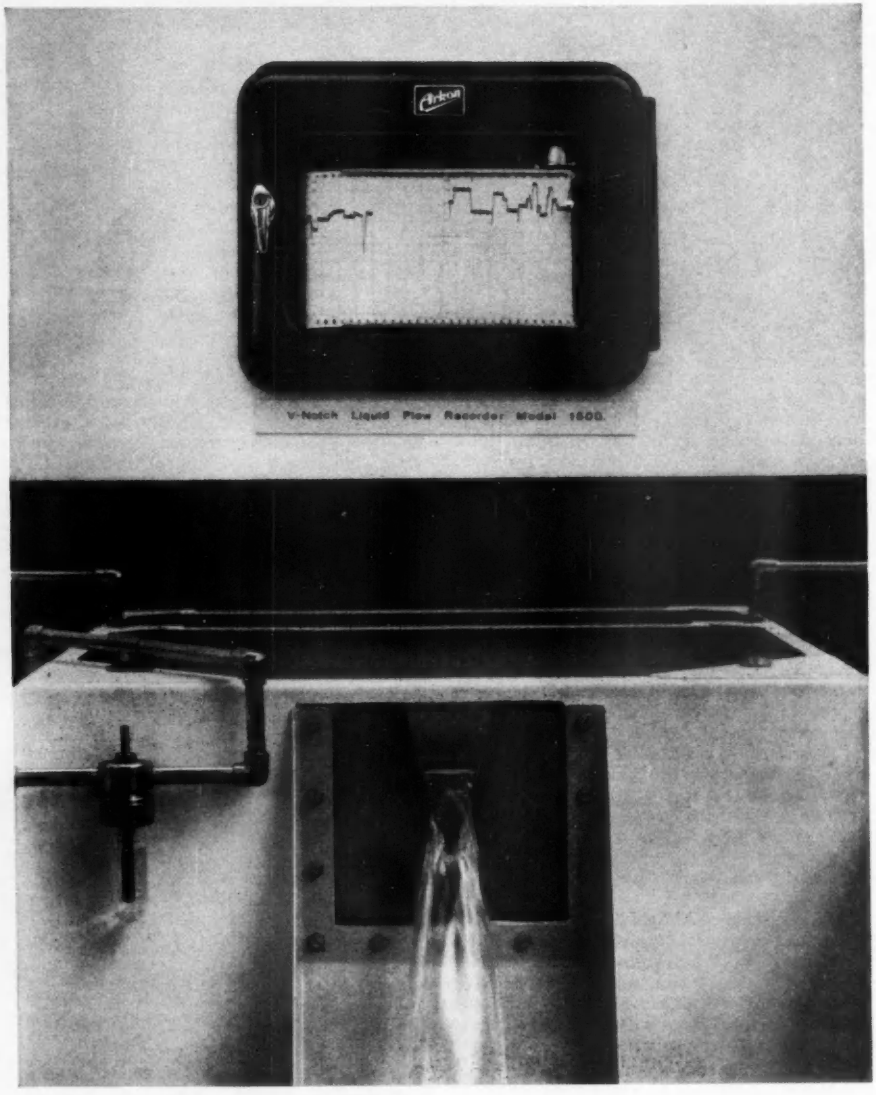

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the plug-board, according to the preselected programme sequence. In addition, automatic spindle-speed changes during the cycle can be programmed, while the slide units can be operated in combined or successive sequences in accordance with a preselected cycle.

The headstock has a direct-coupled drive from a 15-25 hp motor, depending on requirements. Two automatic spindle-speed changes in the ratio of 3 : 1 are obtained with a single-speed motor, or four changes in the ratio of 6 : 1 with a two-speed motor. The swing over the bed of the machine is about 17 in., the swing over the carriage slide is about 11¾ in., and the distance between centres is 30 in. or 47 in. The hydraulic power equipment, complete with its pump and accessories, is a self-contained unit located behind the headstock and easily accessible.

The Newall Engineering Co. Ltd.

In addition to their principal exhibit, the "Contimatic 1520" precision milling and boring machine, incorporating the A.E.I. "Numeritrol" system of continuous numerical control of three axes, as described in detail in our survey on "Recent Developments in the Numerical Control of Machine Tools" in this issue, The Newall Engineering Co. Ltd., of Peterborough, will exhibit a model layout of a complete crankshaft-grinding assembly. This layout, which is intended to demonstrate one of the major activities of the Newall Group of companies, is composed entirely of products of the organization and incorporates recently developed multi-wheel machines, automatic crankpin grinders, and unit-built cylindrical grinding machines, the assembly being based on an output requirement of 60 finish-machined crankshafts per hour.

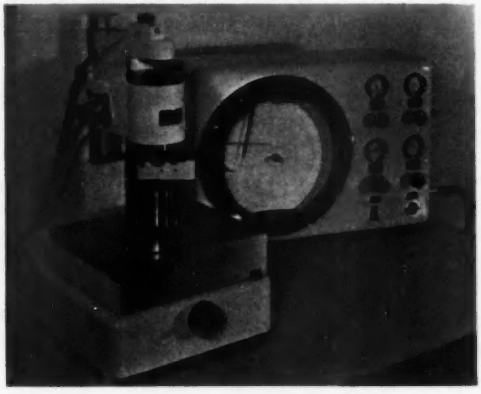

Fig. 9.

Other Newall exhibits will feature a wide range of inspection and machine-tool auxiliary equipment, including high-precision optical rotary and rotary/inclinable tables from the extensive O.M.T. range, with platen diameters from 8 to 36 in. A 30-in. table, incorporating the E.M.I. numerically controlled positioning system, will also be demonstrated. This heavy-duty table is designed to sustain a load of 1200 lb, and the unit has provision for automatic, semi-automatic, or manual control, with a setting accuracy of ±3 seconds. In addition, the O.M.T. roundness-measuring machine illustrated in Fig. 9 will be exhibited. This machine, a recent addition to the series of high-precision inspection equipment manufactured by the company, was developed in conjunction with the National Engineering Laboratory and incorporates a power-rotated pneumatic gauging pick-up, the signals from which are amplified and fed to a large-diameter chart in a recording unit. This instrument has a measuring range of internal diameters of from ⅛ to 8 in., and for external diameters of from ⅛ to 6 in.

The Motion of a Ball in a Ball Bearing

(*Concluded from page 144*)

ball was inserted was specified by the angle measured from the centre of the offset hole in the direction of revolution of the cage. Thus, the 0° hole (offset hole) and the 45° and 180° holes occupied the external position, while the 90°, 135°, 225°, and 270° holes occupied the internal position, and a 315° hole occupied an intermediate position. The cage was supported by the balls in three external holes. The four internal balls were assumed to be free from contact with the inner race, and this was confirmed by the fact that slip occurred at the internal holes and that negative values were obtained at the external holes. The negative slip represents the overrun of the ball as a result of the offset of the ball centre. In the case of the intermediate 315° hole, the ball showed a small positive slip at the lower speeds.

It was also found that the spin ε, calculated from eq. (6), was larger at the 90° and 225° holes than at the 130° and 270° holes, so that it can be concluded that the larger is the offset of the ball centre from the plane of symmetry of the bearing, the greater is the spin of the ball. The results obtained with the smaller offset of 0·15 mm also supported this conclusion, the contact of the balls being much looser, except at the offset hole with negative slip occurring only at this hole. It was also established that an appreciable spin is associated with negative slip. The spin associated with positive slip is considered to have no harmful influence on the operation of the bearing, as it occurs on the unloaded side. In contrast, negative slip is caused by asymmetrical contact of the ball with the grooves of the outer rings, so that a detrimental effect on spin becomes inevitable.

Conclusions

Using a magnetized ball to follow the behaviour of a ball in a ball bearing under radial loads, it has been found that the motion of the ball is three-dimensional and is associated with slip and spin. The conclusions derived from this investigation can be summarized as follows:—

(1) Slip of the ball occurs at the unloaded side, where its contact with the raceways is looser. Slip decreases with increasing speed and load, and increases with radial clearance.
(2) The instantaneous rolling axis relative to the ball changes in a regular manner, the change being closely related to slip.
(3) The cause of the change in the rolling axis is spin during slip, with the angular displacement of spin proportional to the mean slip.
(4) Spin increases with asymmetry of the contact of the ball with the cage or with the grooves of the races.
(5) A further increase in asymmetry causes negative slip. Under a pure thrust load, no slip is observed, and in this case contact is considered to be maintained.

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British Industrial Developments

Individual and Collective Control System for Production Units

The "Productograph", for which Adrema Ltd., of London, W.3, have the marketing and assembly rights for the U.K. from the German firm of Siemens-Halske, is believed to be the most advanced system ever devised for the recording and writing of full production data from individual operating units in a production process. Essentially, information is obtained by means of transducers on such equipment as individual machine tools, packaging machinery, power presses, conveyor systems, looms, steam engines, electric motors, internal combustion engines, and food-manufacturing machinery, as well as in continuous production processes, such as those used in the manufacture of metal strip, plastic film, and paper. They can also be used as flowmeters capable of registering very small or very large quantities of air, gases, oil, water, solvents, slurries, etc. One application of the "Productograph" is illustrated in Fig. 1, which shows the system in operation at the works of Adrema Ltd. for controlling twenty machine tools in the machine shop. This installation is believed to be the first in the world for the control of machine tools in this way.

Fig. 1.

The transducers are impulse transmitters which enable the many types of machines, flow lines, etc., to transmit their data by wire to the "Productograph" control centre in the form of electrical signals, which are subsequently amplified and fed into the various sections of the system. The control centre, which can deal with 20, 40, 60, 100, or 200 transducer sources of information, consists of several units, these being a linear counter for the visual production recording of each unit in a workshop or factory, electrical counters for recording the quantity of product produced and the production time consumed, an integrator for group control, a machine diagram recorder, a high-speed recorder for extended work analysis, a telecommunications system, and a tape recorder.

In the linear counter (Fig. 2), the production process is optically reproduced by means of two film tapes passing behind a scale having thirty units of 10. Of these two tapes, one (on the left of the panel) is blue and shows the actual state of production, while the other tape (on the right) is yellow and is preset to show the required amount of production. By means of a decade plug, each unit can represent 10, 100, or 1000 production units, according to the type of product. When the blue tape meets the yellow tape, a green overlap is produced, instantly showing that the required amount of production has been reached. This state can also be signalled automatically to the plant operator, who may then transfer to other production. Each linear-counter console has twenty production lines, thus enabling the supervisor or production manager to have a co-ordinated view of a workshop or of a section of it.

By means of six-digit electrical counters adjacent to each tape-counter system, such data as machine production times and total idling time can be seen at any moment. On the main "Productograph" console is an integrated unit of six counters for indicating the integrated machine-operating time, the total idling-time causes for up to 200 machines, etc. Any machine can easily be excluded, if required.

The integrator for group control is a lamp panel with small squares which are illuminated so as to provide an instantaneous overall view of the operation of each production unit at any given time. In this way, it is possible to see at a glance which machines are operating or are idle because of setting up, breakdown, tool breakage, lack of material, etc.

The machine diagram recorder or "Productograph" diagram is the heart of the system. In this unit, the impulses from the transducers operate two needles, one of which scratches on a special inkless waxed paper a linear diagram showing the actual operating and standstill times of the machine, while the second needle indicates below the causes of standstill and production speed (actual number of items in units, tens, or hundreds). The recorder, which moves at a speed of 0·5 mm/min, records continuously the production cycles of up to twenty machines per recording unit on twenty double tracks, and simplifies the work-study approach to assembly or production lines or to workshops and plant. Also, it enables fatigue time experienced by operators to be discovered easily.

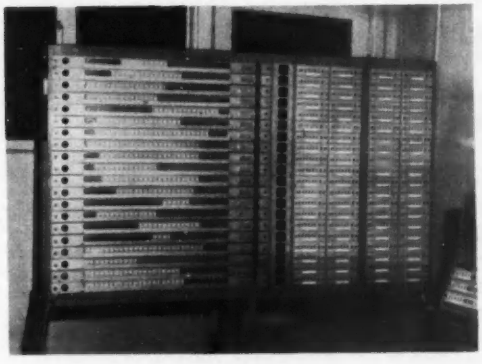

Fig. 2.

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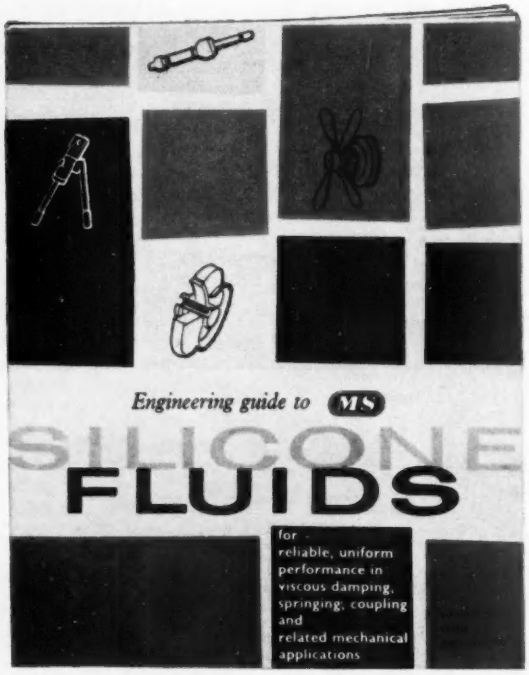
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When a detailed analysis of a particular machine is required, e.g., when dealing with a new method or product, the high-speed recorder, which records one machine on a single strip moving at 30 mm/min, is used. This recorder is especially suitable for operating analyses and can be connected with any machine by pressing the requisite button. Even where processes follow one another in rapid succession, it enables all irregularities to be observed clearly.

Up to five causes of standstill are conveyed to the machine diagram recorder by the machine operator, who merely presses a button on a key-operated interruption switch. This switch, often combined with the telecommunications system to the "Productograph", has a number of coloured square buttons or keys, mounted at the operator's station or machine. When his work is interrupted for any cause, the operator presses the requisite button keyed to that cause. The recorder and indicators at the "Productograph" console are relevantly actuated. A warning light comes on when the transducer on the machine indicates an interruption to production, and this is also indicated at the "Productograph". Thus, the operator is quickly reminded to press the appropriate key. When production starts, the transducer signal automatically releases the pressed key back to normal.

The telecommunications system, which is installed on the "Productograph" console, enables communication to be made with the machine operator, and (through desk extensions) to production managers, works managers, foremen, supervisor stores, etc., so that direct contact is possible between production, control, and administration. Communication is, naturally, two-way, and the "ringing" is effected by lamp signals.

The tape recorder enables all conversations on the telecommunications system or at the "Productograph" console, operating instructions for night staff and operators, and reports from works staff and operators to be recorded when required. This information can then be played back when needed, such as on the morning after night work or for the repetition of instructions. The "Productograph" installation can be switched on and off automatically by means of a timer.

Acid Gold-Plating Solution

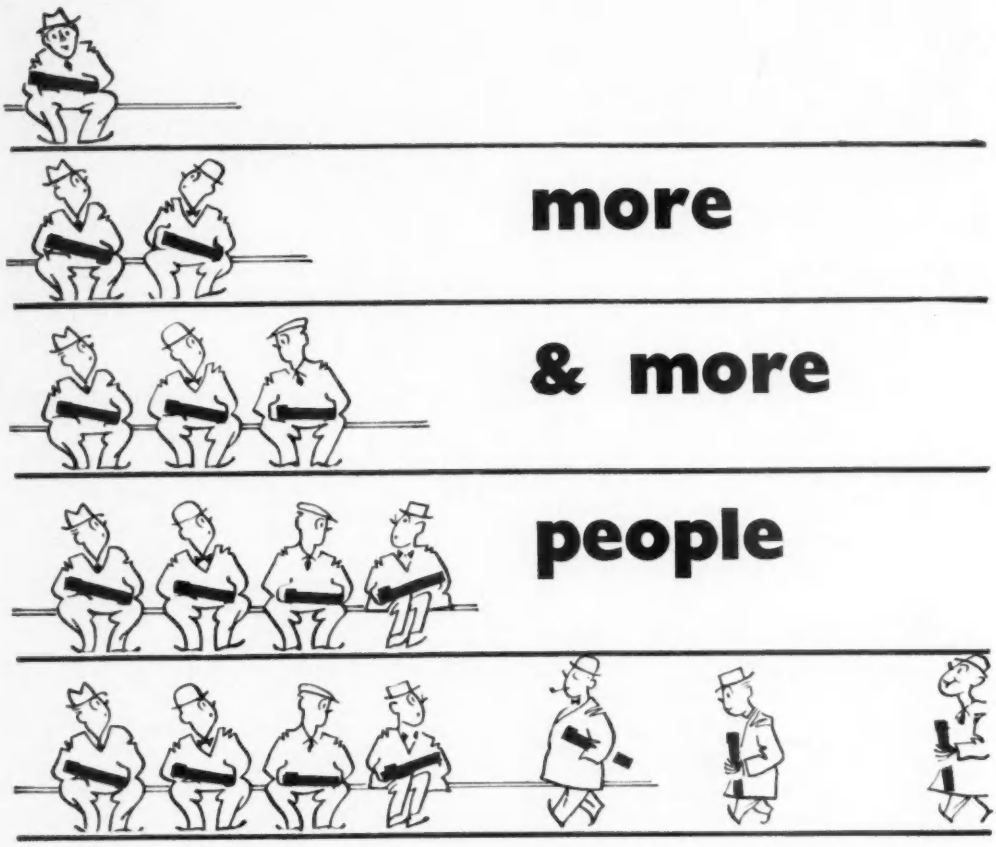
The Engelhard acid gold-plating solution, announced by Engelhard Industries Ltd., Baker Platinum Division, of London, W.C.1, has been developed to provide an electrolyte which will produce a pure gold deposit of high hardness (not less than 100 DPN) and which is not harmful to such materials as printed-circuit adhesives. The process is readily controlled and, compared with more conventional processes, has a throwing power which is at least as good. The deposits produced are of low stress and porosity, can readily be soldered, and have a low electrical contact resistance. Also, because of their high hardness, they have superior mechanical properties to those obtained from conventional fine-gold solutions. Following a suitable pretreatment, the deposits can be applied directly to silver, nickel, and copper, and to their alloys, including copper-beryllium, phosphor-bronze, and nickel-silver. With most other base metals, it is recommended that an undercoat of silver, nickel, or copper be applied.

For small plating installations, heat-resistant glass vessels are quite satisfactory, but the use of water-jackets is advocated, if only for reasons of safety. For larger installations, rubber-lined mild-steel tanks are completely satisfactory. Heating is required under certain operational conditions and, since temperature control is desirable, thermostatically controlled immersion heaters should be used. The working voltage is from 1·5 to 3 V, and this can conveniently be supplied by a generator or full-wave rectifier capable of providing a reasonably smooth d.c. output. Equipment for continuous filtration is not necessary, but periodic filtration is desirable to ensure the production of smooth deposits. Optimum operation is ensured by the use of insoluble anodes. Pure platinum sheet can be used for this purpose, but an entirely satisfactory and cheaper alternative is platinum-coated titanium, which makes it possible to provide large anode areas, giving excellent current distribution over the articles being plated.

The electrolyte consists of from 1 to 500 gm/litre of gold potassium cyanide [$KAu(CN)_2$], from 5 to 500 gm/litre of diammonium hydrogen orthophosphate [$(NH_4)_2HOP_4$], and from 5 to 500 gm/litre of potassium dihydrogen orthophosphate [KH_2PO_4]. Using the same basic solution, but with different gold contents, a range of operating conditions can be obtained for different applications, to produce deposits whose appearance varies from matte through semi-bright to fully bright. The operational variables of importance are the degree of agitation of the cathode, the cathode current density, the pH-value of the solution and its degree of concentration, and the temperature, each of which can have a considerable effect on the nature of the deposits obtained and the efficiency of operation.

With regard to agitation, a suitable amount of movement is 300 ipm, this being described as moderate cathode agitation. It should be noted that cathode efficiency decreases rapidly at agitation rates of less than 300 ipm, but does not increase materially with more vigorous agitation. However, the use of vigorous agitation does increase progressively the maximum permissible cathode-current density which can be used before roughness and porosity are encountered. A typical average cathode-current density is 8 A/sq ft, but its value will depend on the shape and size of the articles being plated and, in conjunction with the degree of solution concentration, will affect the plating time. In fact, the use of more vigorous agitation and higher solution concentration can have a remarkable effect on appearance, cathode efficiency, and the maximum permissible cathode-current density.

The recommended pH-value of the solution is between about 5·2 and 5·8. Although higher pH-values do not effect a marked improvement in cathode efficiency, they tend to make the deposit become progressively more matte. On the other hand, while lower pH-values give rise to a marked decrease in cathode efficiency, they do not affect appearance until below pH 4·0, when the separation of an insoluble gold compound causes roughness, while the loss in efficiency tends to cause porosity. Insofar as solution concentration is concerned, it may be said that both cathode efficiency and the maximum permissible cathode-current density are affected by solution concentration. When industrial thicknesses are required, gold contents of from 7 to about 28 gm/litre can advantageously be employed. For decorative thicknesses, lower concentrations are recommended, but the concentration should in no case be allowed to fall below about 1·7 gm/litre, as the effect known as "burning" will occur, even at low current densities. In general, the solution concentration should not fall below 80% of



use Eclipse

'Eclipse' hacksaw blades and other tools are made by James Neill & Co. (Sheffield) Ltd. and are obtainable from all tool distributors.
UH 35

the nominal value and, as the process uses insoluble anodes, metal plated from the solution must be replaced by the addition of a gold compound. This can conveniently be added in the form of a liquid concentrate which merely requires volumetric measurement.

An example of typical operating conditions is a cathode-current density of 8 A/sq ft, a solution concentration with a gold content of 7 gm/litre, a pH-value of 5·2 to 5·8, and a temperature of 70 to 75°C, with moderate to vigorous agitation of the cathode.

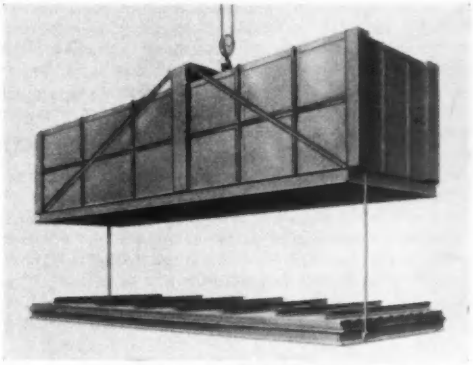
As the gold is in the monovalent state, the process under these conditions will deposit 0·123 gm of gold per ampere-minute, assuming a cathode efficiency of 100%, representing a deposit of about 25·4 microns in 50 minutes. It should be noted that, within the temperature range given, the deposit is of a light colour and is semi-bright. Under these operating conditions, some brightness will be lost at either side of this temperature range, and at low temperatures the deposit will be quite matte and dark. If the gold content of the solution is doubled to 14 gm/litre, a thickness of 25·4 microns can be deposited in 25 min, using a cathode-current density of 16 A/sq ft, without loss of appearance. Within the temperature range of 60 to 65°C, an almost fully bright deposit of attractive appearance can be obtained at 16 A/sq ft, using a gold concentration of 21 gm/litre, while a bright pure-gold deposit can be obtained with an electrolyte containing 28 gm/litre of gold at room temperature, using a cathode-current density of from 12 to 20 A/sq ft and vigorous agitation of the cathode.

Lightweight Bell-Type Furnace

A new lightweight bell-type furnace, embodying a low thermal mass form of construction, has been specifically designed by G.W.B. Furnaces Ltd., of Dudley, Worcs., in conjunction with the South of Scotland Electricity Board, to achieve a predetermined heating and cooling cycle, but at the same time to keep its weight, price, and running costs down to a practicable minimum, bearing in mind the large physical proportions involved. Although the furnace is also suitable for annealing and normalizing, it has been primarily designed for the stress-relieving of heavy charges, such as heavy welded fabrications, cast-iron bedplates, pressure vessels, and boiler shells, which should ideally be stress-relieved in one piece to obtain the required uniformity.

Stress-relieving involves heating to a temperature normally within the range between 600 and 650°C, holding at this temperature for a period dependent upon the maximum metal thickness, and finally cooling down to 300°C at a predetermined rate. Cooling below 300°C may be carried out in still air. The permissible temperature variation throughout the charge being treated is up to 150°C during heating and up to 50°C when at the holding temperature. The specified temperature is the actual temperature at any part of the charge, and is determined by thermocouples attached to the vessel being treated. All temperatures are continuously and automatically recorded. Stress-relieving can also be carried out below 600°C, provided that the heating time is increased proportionately as the process temperature is reduced.

The heating-bell casing has a sturdy fabricated mild-steel structure, incorporating a main carrying frame of rolled-steel sections with a single-point lifting eye. This casing is lined with low thermal-mass insulation embody-



ing specially moulded semirefractory element support bricks. Nickel-chromium heating elements, in coil form, are set in the sidewalls and roof of the chamber, all element connections being made externally in high-conductivity copper and enclosed in ventilated sheet-steel terminal boxes. Working with this bell heating unit is a charge-supporting base, comprising a mild-steel structure, adequately insulated, and topped with semirefractory brickwork. Additional heating elements are accommodated in grooves provided in this surface refractory. The heating elements are automatically energized when the bell is lowered into position. Charge-support members are provided, carried on mild-steel posts which pass through the hearth insulation, so that the charge load bears directly on the steel base structure. To ensure correct alignment of the bell when hoisting or lowering, guide-posts are fitted at opposing corners of the base. The furnace rating is arranged in an appropriate number of zones, depending on the chamber size, and the process cycle is governed by a programme controller. Permanent records of each treatment are provided by a supplementary recording instrument.

Quick-Filling Pressure Regulator for Closed Vessels

The time taken to fill a vessel with steam to a required pressure can now be reduced very considerably by means of a special quick-filling attachment introduced by Sir W. H. Bailey & Co. Ltd., of Patricroft, Manchester. This time reduction is obviously important in such applications as hospital sterilization, but it can also mean increased production in various industrial processes by enabling the time taken for a given operating cycle to be considerably reduced.

The patented attachment, which can be supplied as a conversion unit for existing Bailey Class-G3 reducing valves or already incorporated into new Class-G3 or Class-A valves, obviates the delay inherent in the use of all conventional reducing valves, in which the rate of pressure build-up rapidly decreases as the required setting is approached. The attachment allows full flow through the reducing valve to be maintained until the set pressure is very nearly attained by delaying the regulating action of the reduced pressure. Thus, at about 2 psi below the required pressure, a special diaphragm control valve lifts to admit steam to the underside of the diaphragm of the reducing valve, which then assumes control in the normal way. Conversely, an increase in flow and a corresponding drop in reduced pressure cause the

"any other form of water heater would have been extortionate"

and not so convenient, immediate, or economical.

The Works Director was talking about Leonard steam water heaters which, from available steam and cold water lines, provide abundant thermostatically-controlled water at low cost.

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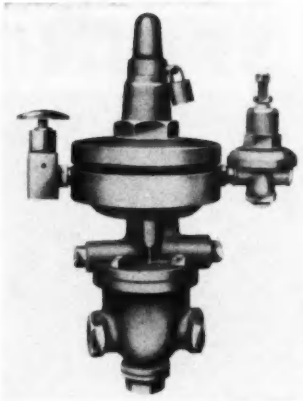


diaphragm control valve to close and the reducing valve to open wide. In actual operation, very sensitive control is achieved by adjusting a needle valve.

As an example of the efficiency of the new attachment, it may be mentioned that typical tests on filling a closed vessel to a pressure of 32 psi showed that, with a conventional valve, the pressure increased rapidly to about 22 psi in 1 min, the rate of pressure build-up then falling off sharply, so that a pressure of 30 psi was reached in about 4 min, and 32 psi in from 6 to 7 min. On the other hand, with the new attachment, the pressure built up rapidly to 30 psi in 1 min, finally reaching 32 psi in 1·5 min.

Solventless Epoxy Resin and Hardener for "Trickle Impregnation"

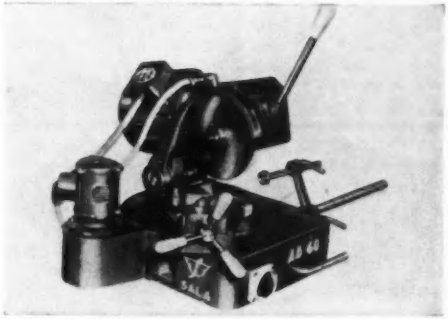
Specially formulated for "trickle-impregnation" techniques, "Dobeckot" trickle resin No. 605, in combination with a special hardener, designated No. 761, has been developed by Dr. Beck & Co. (England) Ltd., of Slinfold, near Horsham, Sussex. The resin and hardener cure without the evolution of volatile matter, giving a void-free impregnation, and the properties of the resin are such that it is particularly suitable for the mass processing of such components as high-speed machine-tool armatures. Thus, armatures treated by this trickle-impregnation technique exhibit all the technical advantages of an encapsulated component without the cost and time-consuming disadvantages of conventional processing based on the use of moulds, while the good penetration of the resin system ensures complete filling of the windings.

Among other advantages of the impregnation technique utilizing the No. 605 resin are increased mechanical strength, especially at high temperatures, excellent resistance to humidity and chemical contaminants, and negligible wastage of material as a result of drainage. Also, bandage and taping operations for securing the winding are in most cases unnecessary, and mass-processing techniques can be devised to ensure maximum savings in the time required for application and curing of the impregnant, compared with conventional impregnation methods.

In operation, 100 parts by weight of the trickle resin are thoroughly mixed at room temperature with 35 parts by weight of the hardener, the pot life of the combination being from 40 to 60 min, depending on ambient temperature and batch size. For the mass processing of windings, a suitable method is to feed the components of the resin system from separate containers into a mixing nozzle immediately prior to application. Tedious cleaning operations can be avoided by blanking off one of the supply lines and flushing the mixing nozzle with pure resin. A particular advantage of this procedure is that the resin-hardener combination is supplied at a constant viscosity. The resin is directed at an angle in the form of a thin stream or as drops onto the rotating winding (preheated to between 100 and 120°C, depending on size). In the case of small armatures, an application angle of 8 deg. and a rotational speed of 30 rpm have been found suitable. At the end of the trickling period, rotation of the component is continued until the resin sets to a firm gel. Finally, to ensure optimum properties, the impregnated winding, following gel, is given a cure of 1 hr at 120°C.

High-Speed Cutting-off Machine

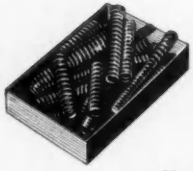
The Model AB60e high-speed cutting-off machine, manufactured in Italy by Sala and introduced into the U.K. by Soag Machine Tools Ltd., of London, S.E.11, is a circular saw of exceptionally high cutting capacity, capable of producing clean, square cuts without work-hardening of the ends through overheating. The cutting speed is between 132 and 265 fpm, and the special high-speed blade used is guaranteed to stand up to the severest working conditions. Typical cutting times are 15 sec for a 1½-in. I-section, 20 sec for a 2-in. T-section, 7 sec for a 1½ × ¼ in. bar, and 30 sec for a bar of 1½ in. diameter.



The machine, which can handle work up to 2½ in. diameter at 90 or 45 deg., is of extremely rigid construction, with the cutter head well balanced to ensure ease of operation. The heavy-duty spindle runs in adjustable taper roller bearings, and the drive to the blade is through a gearbox with hardened gears running in oil. A steady flow of coolant is supplied to the blade and returns through a filter into a settling tank in the machine base, the tank being provided with a large opening to facilitate cleaning. For production operations, the length-stop can be swung clear of the work and can be re-indexed by means of a lever. In this machine, the head, not the vice, rotates for mitre-cutting, so that there is no need to provide extra space to swing long workpieces to the required angle. An engraved scale is provided for reading the angle of cut, which can be set up to 45 deg. in either direction. The patented universal vice has been designed to give maximum support at all cutting angles and has two-position jaw pads formed to grip angles and T-sections securely, as well as flat and round material.

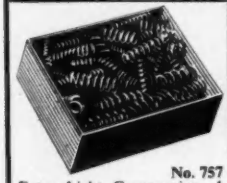
EXPERIMENTAL SPRINGS?

No. 1200
Three dozen Assorted Light Expansion Springs, suitable for carburettor control, etc. **15/-.**

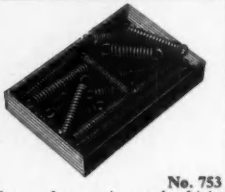


No. 760
Three dozen Assorted Light Compression Springs. 1" to 4" long, 22 to 18 S.W.G., ¼" to ½" diam. **7/6.**

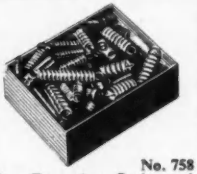
No. 98A
Three dozen Assorted 1" to 4" long, ½" to ⅝" diam., 19G to 15G. **6/6.**



No. 757
Extra Light Compression, 1 gross Assorted, ¼" to ⅜" diam., 1" to 2½" long, 27 to 19 S.W.G. **18/-.**



No. 753
Three dozen Assorted Light Expansion ¼" to ½" diam., 2" to 6" long, 22 to 18 S.W.G. **12/-.**



No. 758
Fine Expansion Springs. 1 gross Assorted ½" to ⅝" diam., ½" to 2" long, 27 to 20 S.W.G. **18/-.**

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Ultra-High-Power Electron Microscope

Stated to be the most powerful electron microscope in the world and the first of its kind in the U.S.A., the Norelco EM-200 electron microscope announced by Philips Electronic Instruments, of Mount Vernon, New York, provides a direct magnification of from ×300 to ×200,000 and, with photographic enlargment, of over ×2,000,000. In addition to high stability for optimum performance and rapid, smooth operation, the instrument, which has a resolving power consistently below 10 Å, has such outstanding features as compensation of astigmatism in less than 1 min, change-over for single or double condenser-lens operation in 30 sec, complete column alignment in 30 min, and the easy accommodation of specimen-treatment devices. Accelerating voltages of 40, 60, 80, and 100 kV can be obtained, and the settings can be changed during operation.

Focusing at magnifications up to about ×20,000 is accomplished rapidly with a wobbler device. For critical focusing at high magnifications, use is made of a binocular viewer (×9) and a fine-grain flourescent screen, which can be tilted perpendicular to the viewing axis. Fine-focus control is adjustable in steps of 0·05, 0·1, 0·2, and 0·4 micron. In addition to visual observation on the large fluorescent screen, specimens can be photographed by means of a 3¼ × 4 in. plate camera or a 40-exposure camera using 35-mm film, each camera being provided with an automatic exposure index. An electronic exposure-meter measures the average light intensity of the entire image or of a specific detail, as required. An electrically controlled shutter handles time exposures and preset exposures from 0·5 to 60 sec, the exposure-time and push-button shutter controls being located on the control panel in easy reach of the operator. The shutter can be partially opened to register two exposures on a single plate, while stereo-micrographs can be handled with a standard holder at angles of ±6 deg. The instrument includes a vacuum desiccating chamber for both films and plates. Dark-field microscopy is easily accomplished.

The condenser and objective lenses are each provided with electromagnetic stigmators which can be centred to avoid image shift during compensation. Objective-lens astigmatism can be compensated to less than 0·1 micron, and compensation is possible on any specimen, simultaneously with focussing, at magnifications of ×20,000 and higher. To prevent specimen contamination and to reduce aperture contamination, the specimen chamber can be cooled to about −90°C. The evacuation time after changing a specimen is 20 sec.

Cathodic-Protection Systems for Ships and Boats

Designed to provide complete cathodic protection against corrosion of the underwater hulls, rudders, and propellers of large and small ships, the Reader system of cathodic protection, developed by the Cathodic Protection Division of E. Reader & Sons Ltd., of London, E.C.4, comprises three basic types, i.e., the "Readermatic" system, the "Readermajor" system, and the "Readerminor" system.

The "Readermatic" system is a fully automatic cathodic-protection system for the prevention of hull corrosion and is primarily designed for the larger ships, such as passenger liners, tankers, and general cargo vessels, which all encounter widely varying conditions in the course of their duties. This system automatically provides the correct level of current under all these conditions. In this connection, it should be appreciated that current for cathodic protection can be derived by the use of sacrificial anodes, which produce a small electric current by their own corrosion in seawater, or the current can take the form of an impressed current, i.e., provided by the ship's power supply. In the "Readermatic" system, impressed current is used and is controlled by a special control unit. This control is actuated from streamlined reference electrodes of zinc attached to the outer hull, and the protection current is varied so that the ship's potential is always sufficiently depressed to provide complete protection and yet controlled in such a way that no area of the ship is over-protected. The cathodic-protection current flows through anodes mounted on the hull. These anodes are of an ennobled lead alloy and are streamlined in form and designed to give maximum current control and a high spread of protection. The anodes are quickly and easily fitted in dry-dock, and hull preparation around the anode is kept to a minimum. The lead anodes, reference electrodes, and automatic control unit form a flexible system

THE MONEY THAT MANAGEMENTS SAVE THROUGH MOBIL ECONOMY SERVICE

More than £6,000 a year at Kellogg Company of Great Britain Limited

KELLOGG COMPANY OF GREAT BRITAIN LTD found that the roll neck bearings used in flake roll machines were averaging only two months' life. So they took their problem to the experts in lubrication—Mobil. Mobil advised the installation of mechanical grease pumps using a special grade of Mobilgrease. The annual cost of replacing the bearings of each of the flake rolls has been £312 . . . but since the introduction of Mobilgrease the life of the bearings has been considerably extended, and there has been no loss of production time through bearing failure. During one year of operation, after applying Mobil's suggestions, Kellogg's made a direct saving of over £6,000 in replacements, maintenance, and production time.

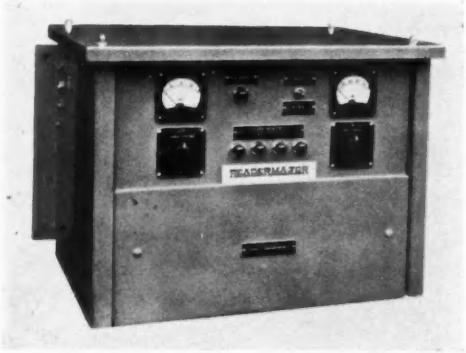
WORLD-WIDE EXPERIENCE OF INDUSTRIAL LUBRICATION This example of the value of Mobil Economy Service is typical of many that could be cited from almost every industrial area of the world. In all these areas, the world-wide Mobil organisation is applying more than 90 years' experience to the cutting of lubrication and maintenance costs.

ONE PLAN TO MEET ALL LUBRICATION NEEDS The value of Mobil Economy Service is the value of expert knowledge methodically applied: it is a matter of assess'ng all the lubrication needs of a business collectively, considering how they can best be met with the fewest different lubricants in the smallest quantities, and making sure that everyone concerned knows how to use the lubricants to the best effect with the absolute minimum of work. The astonishingly large savings that are often achieved are the measure of the experience and skill that Mobil bring to the consideration of every industrial lubrication problem.

Mobil
ECONOMY SERVICE

which can provide the correct degree of protection for any ship, and the range of the controller is such that the system can operate throughout the ship's life without adjustment. A special analogue compensator permits a rapid cathodic protection current response to changes in hull condition and prevents the over-protection that might otherwise occur when the ship enters a fresh-water harbour.

The "Readermajor" system is intended for the smaller ships, such as coasters and trawlers, which have a great variety of duties but which generally operate on a more regular routine and under conditions that are more predictable than those of most large ships. Consequently, they do not require the high degree of stability and accuracy essential in the larger ships and can be protected by a simpler system. Nevertheless, they require a large variation in current between being in harbour and being at sea, and this is taken care of in the "Readermajor" system by means of a simple manual control which enables the current to be displayed on a controller (illustrated). The feature of this system is that it operates with sacrificial anodes for providing the low current required in harbour (when generated electricity is often not available), while impressed current from the ship's supply is used when at sea. The system is so arranged that, when impressed-current protection is in operation, the sacrificial anodes are not consumed, thereby prolonging their life. This combination of sacrificial anodes with impressed current makes it possible to provide a simple two-position control for switching on and off the impressed current as the ship enters and leaves a harbour, the level of the impressed current being easily adjustable. If desired, change-over can be made automatic by means of control actuated by the propeller speed to switch the impressed current on and off and to allow the sacrificial anodes to provide the necessary current when the propeller is not turning.



The "Readerminor" system is the smallest of the Reader systems and provides complete protection against underwater corrosion in small boats by means of an impressed current. Most small craft have a suitable low-voltage electricity-supply source, and the system is designed to operate economically on such a source and to provide a two-level current control which gives adequate protection when the vessel is at sea and when it is in harbour. In the latter case, the current consumption is only a few milliamperes and therefore causes no drain on the battery. In this system, the non-consumable anode is made of platinized titanium, and the amount of current fed through the anode is varied by means of a controller. The system can also be used to prevent corrosion of the rudders and propellers of wooden fishing boats and to provide protection to the keels, rudders, and propellers of yachts.

In addition to these three systems, other Reader systems are available for affording temporary or permanent cathodic protection to ships when fitting out in shipyards. In addition, these systems can be extended to protect ships journeying up rivers across bars and other obstacles, where they may be subject to considerable abrasive action. Other systems are available for the protection of seawater-containing machinery and seawater ballast-tanks, as well as for removing corrosion products already formed, even when they have been contaminated with oils and bitumens.

Rigid Urethane-Foam Potting Material

A new potting material made with rigid urethane foam is stated to be ideal for potting electrical components, as it imposes a minimum of stress on the parts being potted because the foam slowly and uniformly expands and hardens in the potting void. In addition, it affords excellent protection against shock, vibration, corrosion, and humidity, while its density of about 10 to 12 lb/cu ft makes it from six to seven times lighter than conventional potting compounds. Also, its cost is appreciably less than that of many other potting compounds. The rigid urethane-foam potting material is easily prepared by either batch or mechanical mixing of two resins, the mixture then being poured into the void to be potted and allowed to foam and cure. Most foamed parts can be cured at normal room temperature, but in some cases it may be desirable to cure the parts in an oven at 150°F for about 30 min immediately after foaming is completed.

The foam produced from these resins is stated to have excellent dimensional stability at both low and elevated temperatures, and appears to be unaffected by a series of thermal-shock cycles from 200 to −67°F. Thus, it is not cracked or distorted by immersion in liquid nitrogen, while its heat-distortion temperature is above 200°F. Other properties of the material include a tensile strength of 405 psi, a shear strength of 103 psi, a flexural strength of 128 psi, a compressive strength at yield point of 375 psi, and a deflection at yield of 6%.

Emulsifying Burners for Heating Installations

Available in a range of sizes to cater for outputs from 250,000 to 6,000,000 BTU/hr, the Type EOB emulsifying burners announced by the Camron Engineering Co. Ltd., of Chichester, Sussex, are designed to cope with the heavier grades of fuel oil and, indeed, are claimed to render the problem of burning the heavier grades of fuels no greater than that of burning the lighter grades. Thus, these units can burn a 200-seconds fuel oil at normal ambient temperatures, and 960- and 3500-seconds fuel oils at a preheat temperature of only 120°F. Also, the absence of preheater thermostats, solenoid valves, and timers lessens the possibility of flame failure and substantially reduces maintenance.

These burners are equipped with a motor of appropriate size driving a conventional centrifugal blower and a combined pump and compressor unit divided into three separate parts, i.e., a suction gear-pump, a metering pump, and the compressor. Oil is drawn from the supply

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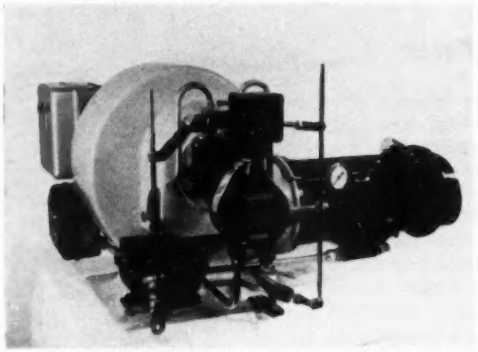
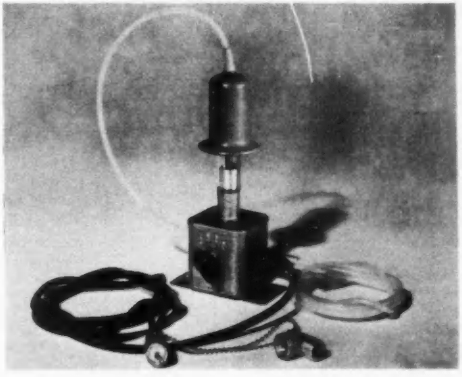


tank or ring main by the gear-pump, delivering the oil to the adjustable metering pump, which controls the firing rate and passes the metered fuel to the compressor. The compressor draws atomizing air through an air control valve, and this air, fed with oil from the metering pump, combines to form an air/oil mixture which is passed to a stabilizer, where the emulsion is partially separated and, in the form of saturated air and oil, is fed by separate pipes to the nozzle, where they are again mixed to form the final atomized mixture. The primary or atomizing air is only a very small part of the air required for combustion, the main or secondary air being provided by the blower through an adjustable air director surrounding the nozzle and controlled by the inlet shutter. Electrical ignition by means of a high-tension spark is incorporated, and access to the nozzle and electrode assembly is facilitated by a detachable cover on the side of the draught tube. On/off, high/low, or fully modulating controls can be provided, as required.

Pulse-Measuring Potentiometer

Intended for the accurate measurement of high-voltage pulses in radar transmitters and other pulse circuitry, the new Type PD.30 pulse-measuring potentiometer announced by Ferranti Ltd., of Dundee, can be built into equipment to provide a permanent facility for pulse-voltage measurement, or can be supplied in a case as a portable test instrument for use in the laboratory. Of compact dimensions and light weight, the instrument essentially comprises a high-voltage vacuum capacitor, internally shielded by a metal cylinder to eliminate the effects of external stray capacitances, and a lower element,



which is either a capacitor for high-voltage division, or a resistor for differentiation, these lower elements being protected by a cold-cathode diode.

High-voltage pulses up to 30 kV can be handled, four ranges being provided by a selector switch which gives two preset voltage-division ratios (normally 250 : 1 and 500 : 1), and two differentiation ratios. The input capacitance of the measuring oscillope used has some effect on calibration, and an allowance of 45 pF has been made for this contingency. On the most sensitive range of 250 : 1, a change of 8·5 pF produces an error of approximately 1%. The top capacitance is 3·4 $\pm$0·2 pF, and the total load capacitance is 6 pF maximum. Connecting leads for both the high-voltage and oscilloscope connections are provided. The shunting effect of connecting-cable capacitance on the resistive element is minimized by inserting the lead through a special plug/socket which incorporates selected terminating resistors. The higher-voltage lead is fitted with a clip which enables the potentiometer to be connected easily across the high-voltage pulse circuit being measured. The oscilloscope used must have a high-impedance input for all ranges.

Meter for Very Low Flow Rates of Oil

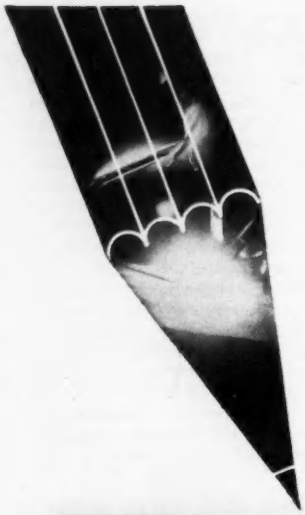
A meter which is capable of measuring with an accuracy within $\pm$1% the flow of fuel oil at rates as low as 1½ gph under heads as low as 2 ft is now available from Walker Crosweller & Co. Ltd., of Cheltenham, Glos. Primarily intended for the measurement of the flow of fuel oil to burners, this meter is stated to provide for the first time an economic method of recording such information in many of the smaller industrial applications, including oil-fired boilers, furnaces, and ovens.

The instrument, which is of the integrating type, is a specially calibrated version of the company's standard ½-in. "Arkon" oil meter, which is normally calibrated to read flows down to 4 gph. An inherent feature of the design of this meter is the use of a nutating-piston principle, in which a flat disc oscillates on its periphery, making it extremely sensitive.

Stereoscopic Projector for Optical Inspection

Intended to replace low-powered bench magnifiers and binocular stereoscopic microscopes in optical-inspection work, a new bench- or machine-mounted stereoscopic projector, announced by Vision Engineering Ltd., of Send, Woking, Surrey, is not designed for measurement but is a form of projector microscope giving magnifications of $\times 7\frac{1}{2}$, $\times 15$, $\times 30$, or $\times 50$.

Providing a stereoscopic image without the need for polarized glasses, etc., and without critical positioning of the head during viewing, the instrument is superior to binocular stereoscopic microscopes in that it provides a larger field of view at any given magnification (e.g., a



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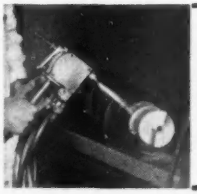

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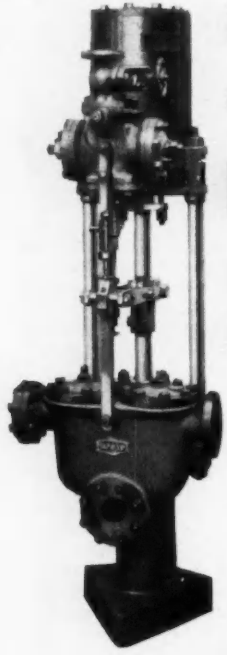

hundreds of thousands ——

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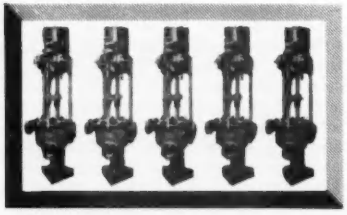

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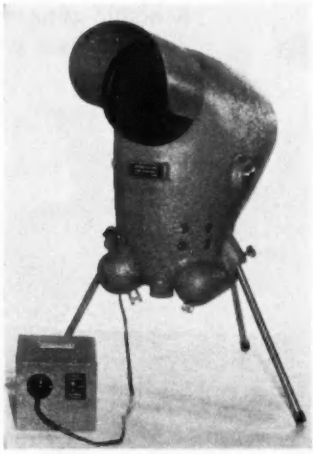

circle of 1 in. diameter at $\times 7\frac{1}{2}$, or twice that of a good stereo-microscope) and also eliminates the eye-strain and fatigue associated with the use of microscope eyepieces after prolonged viewing periods. In addition, a good depth of focus is obtained and viewing can be carried out in daylight. A wide range of accessories is available, including an image inverter for assembly applications, a coaxial illuminating attachment, and internal probe attachments.

Low-Cost Precision Lapping Machine for Flat Surfaces

Although essentially a low-cost unit, the new Engis lapping machine for flat surfaces, developed by Engis Ltd., of Maidstone, Kent, has a performance comparable with that of machines costing from three to five times as much and, indeed, is capable of producing surface finishes down to 1 micro-inch in a matter of minutes. In addition, it is of extremely compact dimensions, measuring only $22 \times 11\frac{1}{2} \times 18$ in. high and weighing about 110 lb. Typical applications include its use in the production of semiconductor materials for experimental purposes and for production runs on such items as pump seals, valve seats, microtome knives, and other components which must be finished to a high degree of exactitude and flatness.

The machine has a rigid cast-iron body surmounted by an integrally cast ring to which a lapping jig or work-holder can be attached. The drive is effected by a $\frac{1}{4}$-hp, 1420-rpm electric motor through self-aligning couplings and a totally enclosed 20 : 1 reduction unit to a vertical spindle which rotates in two self-sealing ball races at about 75 rpm. Five close-grained cast-iron lapping plates, each of 8 in. diameter, are available for use with the machine. These interchangeable plates, which can be dropped onto the spindle head and lifted off, as required, are hand-scraped and then lapped for flatness and surface finish with different grades of "Hyprez" diamond compound, their centre-line average surface finishes ranging from about 1 to 100 micro-inches. When worn, these lapping plates can be resurfaced on master plates of the appropriate grades. As the plates rotate at only 75 rpm, their optimum performance is ensured and the operator can safely hold the work by hand. However, a lapping jig or work-holder suitable for several different shapes and sizes of workpiece is under development. It will be appreciated that, with this machine, stock-removal rates are high and that the progressive lapping obtained obviates the necessity for laborious pretreatment of the workpiece with abrasive papers.

Long-Range Infrared Photoelectric Switching Equipment

Although the use of photoelectric switching units using infrared light beams for the protection of property against intrusion is well known, it is difficult to protect large areas in this way, particularly out of doors, where equipment may be affected by extraneous light sources, such as vehicle headlights. For this reason, the Series MPU.2 long-range photoelectric equipment announced by Lancashire Dynamo Electronic Products Ltd., of Rugeley, Staffs., has been designed for use in applications where the direct line-of-sight distance between light projector and receiver can be as great as 1500 yards.

The problem of spurious operation due to extraneous light has been overcome by the use of a modulated light beam, so that the photoelectric receiver is sensitive only to this modulation. Semiconductor techniques are used exclusively in the receiver unit, and the system is arranged to fail-safe if tampered with. Suitable optical and mechanical arrangements are fitted to enable initial alignment of the two units to be carried out easily. Apart from its obvious application as an intruder alarm, the equipment can also be used for navigational warnings, e.g., to operate fog-warning signals and for on/off signalling in cases where the expense of laying cables would be prohibitive. Various industrial applications are also possible in cases where conventional photoelectric units are inoperable owing to brilliant ambient lighting, e.g., near furnaces.

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Our many years of experience as manufacturers in Natural or Synthetic Rubber are at your disposal.

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Est. 1895

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"Hermetic" Works, Priory Rd., Birmingham 6

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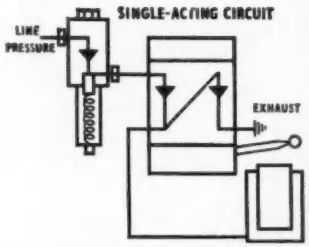
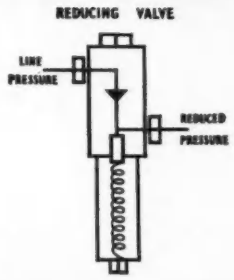
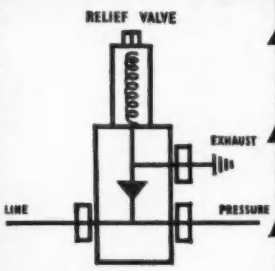
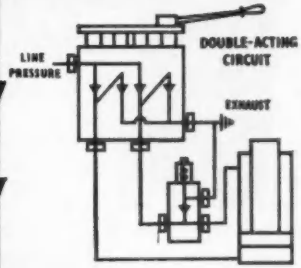
Grams: Hermetic, Birmingham



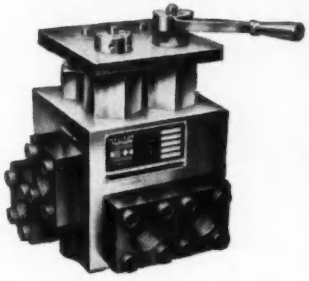
think of a circuit







4-WAY SD VALVE



. . . any circuit. Or think of a hundred circuits, each with a different application in hydraulic control. Then think of Ellisons. Ellison can offer you a specialist-designed, precision-made valve for *every* purpose. For water or oil; hand, foot, air, pilot hydraulic or solenoid operated. And our engineers have a great deal of experience in planning complete circuits which they would be glad to put at your disposal.

We shall be pleased to send further details of the Ellison range of hydraulic valves on request.

ELLISON HYDRAULICS

Division of George Ellison Limited
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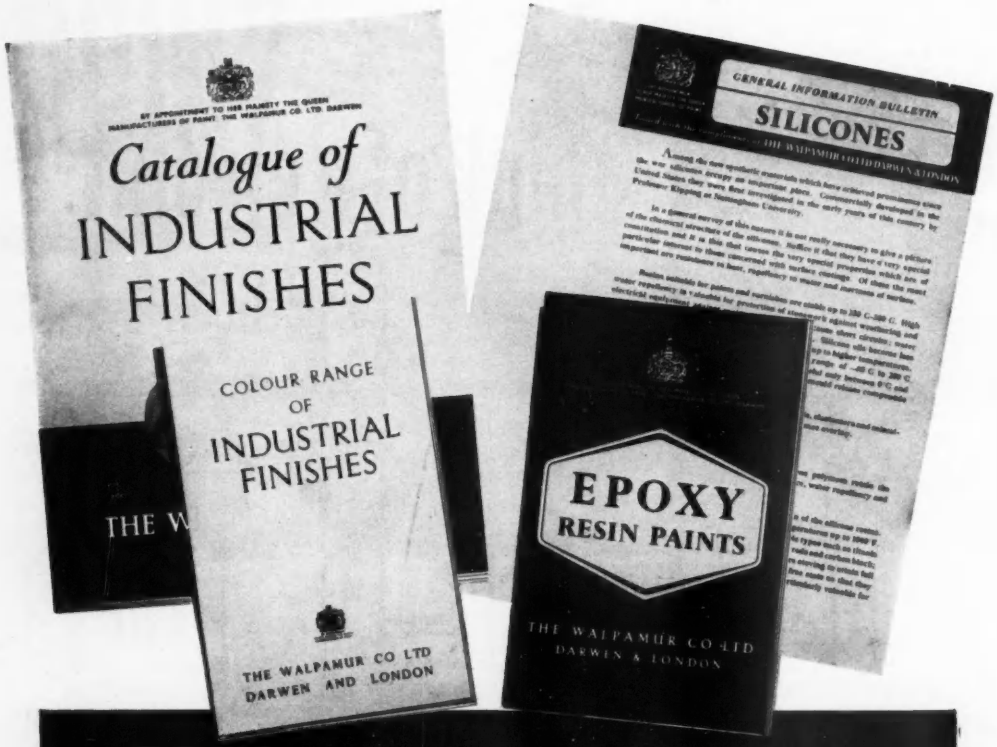

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INTERNAL GRINDER

for production of Injectors and high-precision components

FRATELLI COPPIER MILANO

TECHNICAL CHARACTERISTICS

Internal grinder for holes of 1 to 20 mm diameter in high-hardness alloys, e.g., gauges, dies, etc. Spindle speeds from 60,000 to 140,000 rpm.— Quick adjustment for control of diameters, with automatic feed of the spindle head: automatic stop — Supply voltage according to requirements. Weight of complete Grinder approx. 750 kg.

CONSTRUCTIONAL FEATURES

Grinder specially designed for the mass production of injectors of any type for the internal grinding of gauges and dies in tungsten, carbide and other alloys, for work requiring a very high degree of precision of the order of 0·0003 mm both in roundness and centricity with surface micro-roughness of 0·00025 mm. Perfectly smooth surfaces are obtained, in view of the complete absence of harmful vibrations The perfect finish of the surfaces, combined with exact geometrical shape, is always assured by the M.C.54 Grinder fitted with patented M.C.52 "Turbo Spindles", with automatic take-up of bearing play, oil-mist lubrication, and other features introduced into its construction. All the adjustments of the individual members of the machine are hydraulically controlled. The machine is fitted with turbine-driven spindles of very high rotational speeds, from a minimum of 60,000 to a maximum of 140,000 rpm; one of these spindles serves to grind cylindrical parts and the other conical parts (e.g. injector and valve seats) according to requirements.

The rotating spindle unit of the M.C.52 "Turbo Spindles" employ a small turbine and the hydraulic system adopted, as compared with electrically-driven spindles, affords numerous advantages, including the following :—

- simplicity of construction.
- variable speed range between the limits required, depending upon the internal dimensions to be ground.
- normal operating speed : 120,000 — 130,000 rpm.
- speed variation between full and no load about 3-4 per cent.
- extremely simple automatic lubrication, without the need for cooling equipment.
- possibility of grinding diameters from 1 to 20 mm.
- automatic take-up of bearing play by means of a patented device which guarantees longer life to the bearings.
- operating life of the spindle at least 800 working hours guaranteed.
- high-precision grinding and finishing of the parts.

FRATELLI COPPIER-MILANO (ITALY) PIAZZA CARRARA, n.15

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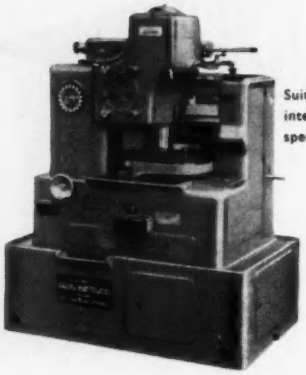


GEAR SHAPERS

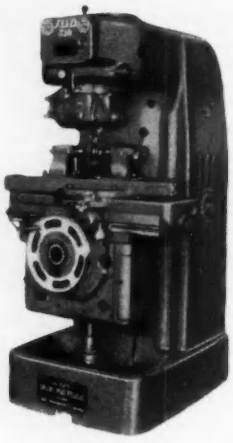
Suitable for cutting external, internal, spur and helical gears, special profiles and racks.

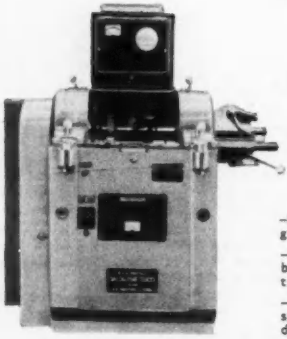
4 Models	Max. Mod.	Max. Ø
SRI 180	4.5	210 mm
SRI 220	5	250 mm.
SRI 6/550	6	550 mm.
RI 8/750	8	800 mm.

SUD 320 UNIVERSAL DIAGONAL GEAR SHAVING MACHINE

for the finishing of cylindrical spur and helical gears through shaving up rotation with a circular shaving cutter.

–Max. gear O.D. to be shaved	320 mm.
–Module	from 1 to 8
–Max. distance between centres	470 mm.





GEAR SOUND TESTING MACHINES

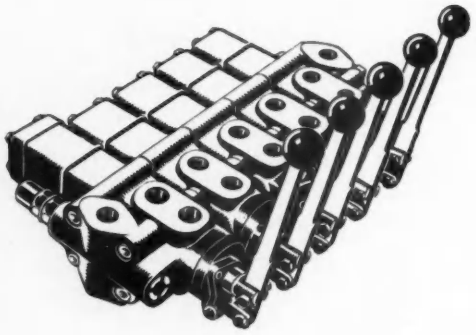
for the gears noise control at different speeds and loads.

	PRI 320 mm.	PRI 500 mm.
–Max. Ø of the gears	320	500
–Max. distance between centres	300	630
–Range spindles centre distance	60 to 200	90 to 350

OTHER PRODUCTS:
Centre lathes, Copying lathes, Spline Shaft Grinders, Hydraulic automatic cycle end facing and Centring Machine, Gear Shaper Cutters, Shaving Cutters, Devices for Gear Shaper Cutters Sharpening, Transmission Gears, Ring Gears and Pinions, Vernier Calipers, Centralised lubrication plants.

DALDI & MATTEUCCI SpA Milano (Italy)
Via Cadamosto 7

CONSTANT PRESSURE need not be wearing



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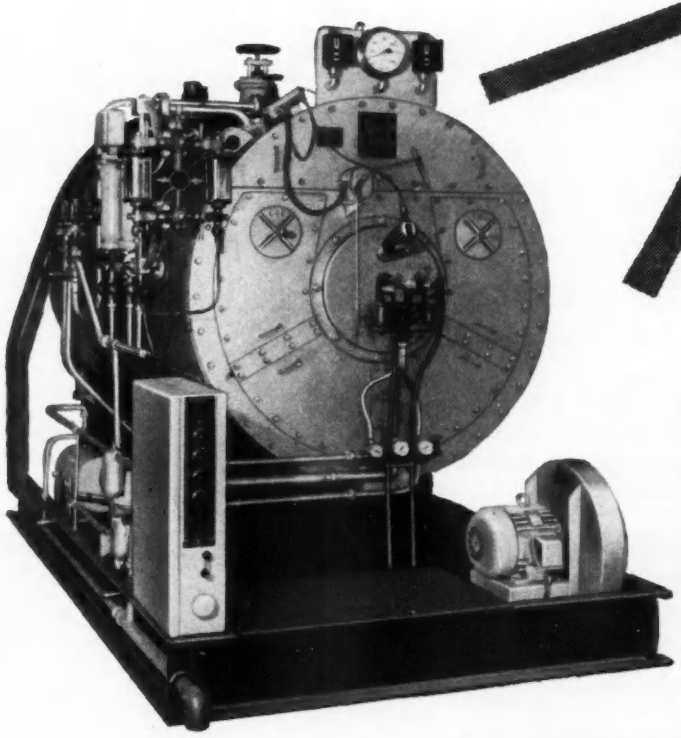

what a holiday for the staff

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The supreme efficiency of the "Steampacket" cuts fuel bills *permanently* and operates without constant staff supervision. It incorporates the very best practice in boiler construction. Write today for full details.

THE CRADLEY BOILER COMPANY LTD.,

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Cradley STEAMPACKET package boiler

NOW... 2 NEW BERCOSTATS

750 and 1000 watts

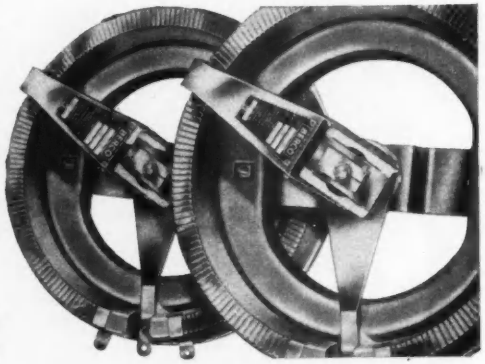
extend the range from 8 to 10 sizes and from 25 to 1000 watts.

Models L750 and L1000 incorporate many new features including:—

- Spindle can be driven from either side and can project on both sides for the ganging of other apparatus.
- Spindle length can be adjusted for different panel thicknesses.
- Brush mounted in gymbals to provide a constant contact area.
- Bercostats accommodate far more steps than stud type regulators of equal capacity and give finer adjustment.

Available protected with steel ventilated covers or ganged with or without covers.

OHMIC VALUE AND CURRENT RATINGS					
Ohms	Current Ratings AMPS		Ohms	Current Ratings AMPS	
	L750	L1000		L750	L1000
1	27.4	31.6	75	3.16	3.65
3	15.8	18.3	100	2.74	3.16
5	12.25	14.2	150	2.24	2.58
7.5	10.0	11.5	200	1.94	2.23
10	8.66	10.0	350	1.46	1.69
15	7.06	8.18	500	1.23	1.43
25	5.48	6.32	1000	.866	1.0
50	3.87	4.47	2500	.548	0.634



BERCO group of companies

List 613D tells you all about them

THE BRITISH ELECTRIC RESISTANCE CO. LTD.
QUEENSWAY · ENFIELD · MIDDLESEX
Tel: HOWard 2411 Grams: Vitrohm Enfield

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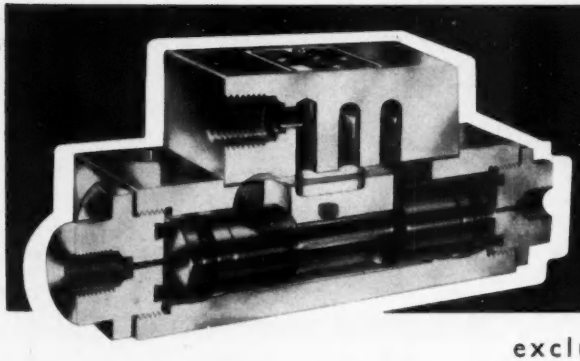


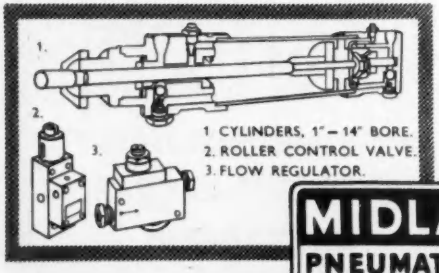
MILLIONS MORE valve reversals

exclusive development

INCREASES VALVE LIFE many times

Midland Pneumatic valves with exclusive "Fluon" valve slides, mean millions more valve reversals. All other parts are bronze or stainless steel. The range, ⅛″—1″ B.S.P. Quick delivery and of course a complete range of cylinders, control valves and air line fittings.

Write for catalogue.



MIDLAND PNEUMATIC LTD
NEW CROSS · WOLVERHAMPTON

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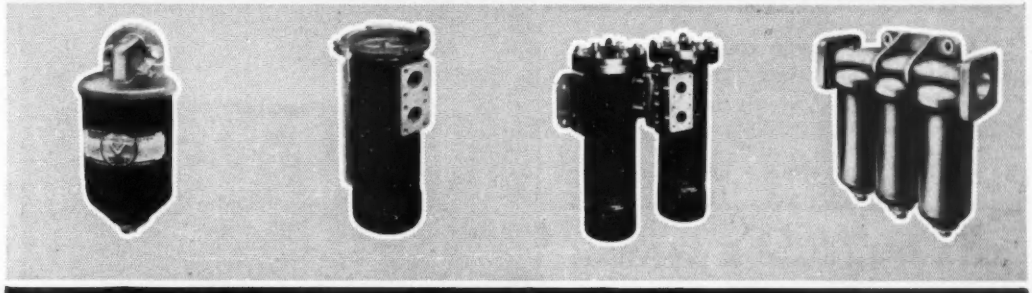
VOKES OIL FILTERS

Vokes filters fitted to your engines save money three ways, for by removing impurities from the lubricating oil they improve engine performance, lengthen engine life and make possible longer periods between servicing. Made and guaranteed by Vokes for the complete protection of modern bearings and gear boxes. Inexpensive on first cost, simple to install and the most economical in use. Please write for full details of the complete range.

Illustrated left is a Vokes single bowl full-flow lubricating oil filter fitted with a by-pass device which ensures a continuous flow of oil should the insert become choked. Manufactured in four sizes with capacities from 750 to 2,000 g.p.h.



Direct mounting type. 200-700 g.p.h. capacities.

'Top Servicing' type with articulated clamp. 3,000-5000 g.p.h. capacities.

Duplex 'Top Servicing' 1000-5000 g.p.h. capacities.

Triple bowl, parallel flow type. 1200 and 1600 g.p.h. capacities.

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S.P.K. Fixed Centre Geared Multi-head fitted to 28in. Vertical Drilling machine using fixture fitted to standard S.P.K. Indexing Table.

Old time, using single spindle drills . . . . 11 mins. 29 secs.

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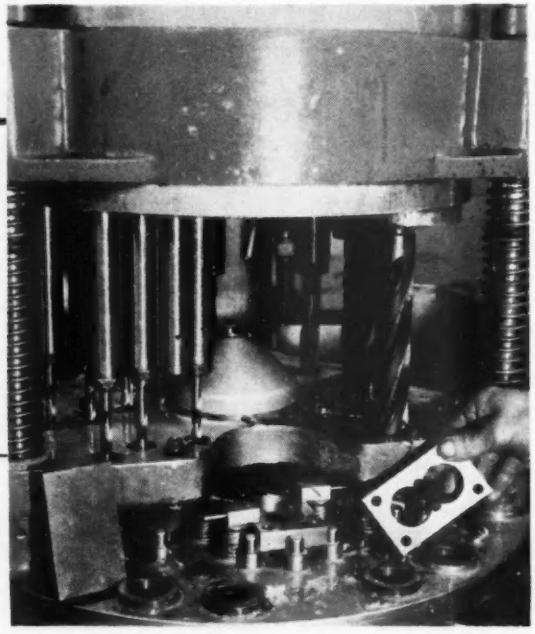

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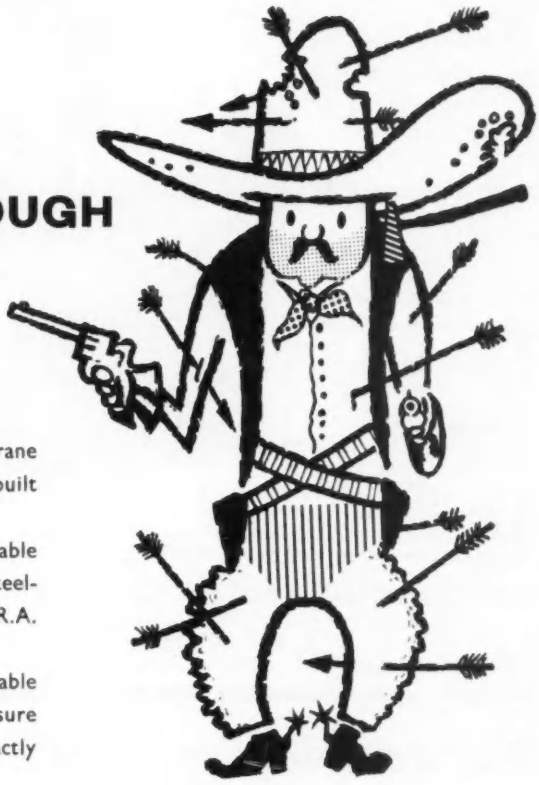
SOME GET IT ROUGH



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Whartons employ a technical staff capable of interpreting the demands of the steel-maker, and designing cranes to B.I.S.R.A. specification.
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It is true to say some get it rough, but a Wharton crane is built to expect it.

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Hydraulic movement

Rapid displacement of the head

TECHNICAL DATA

Principal features of the machine:

Table Stroke	1300 mm
Maximum grinding length	1000 mm
Maximum grinding width	270 mm
Width of clamping table	250 mm
Maximum height of work-piece	370 mm
Rapid replacement of head-remotely controlled	350 mm
Wheel diameter ...	275 mm
Automatic vertical feed	from 0.01 to 0.05 mm

TECHNICAL DATA

Wheel speed	1400 rpm
Adjustable speed of table	from 1 to 20 strokes per min
Electric Motors (3-phase 50-cps) for:	
Wheel rotation (1400 rpm)	8 kW
Hydraulic unit ...	2.5 kW
Rapid displacement ...	0.3 kW
Cooling unit	0.15 kW
Lubricating pump ...	0.1 kW

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The quality and accuracy of measurements obtained with our mass flowmeters are due to the fact that the reading is given directly in terms of weight, the counter being adjusted BEFORE measurements are carried out. No corrections are needed for measurements expressed in terms of volume. This is why our equipment is meeting with increasing favour in an extremely wide range of industries.

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Where the measurement of milk by weight is extremely important, because milk does not have the same density day and night, owing to changes in ambient temperature.

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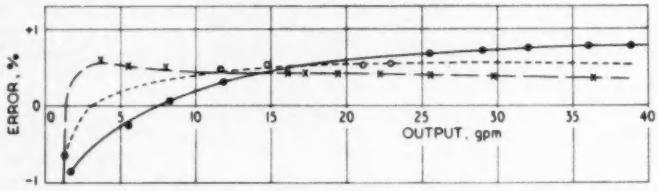
Our flowmeters are used in pipelines as well as in metering installations in refineries. They control the regulation of heating furnaces in glass, cement, and steel works, etc.

CHEMICAL INDUSTRY

In this industry, more than in any other, it is essential to be able to adjust measurements immediately to the densities or the viscosities of the products to be metered.

Adjustment of the meter is effected at the time of calibration, in accordance with the density and viscosity of the liquid concerned. This explains why the accuracy claimed (1%) is truly achieved.

As an example, the results obtained with one of our Aviation Series RAD 64 automatic flowmeters are given in the graph, which is based on measurements by weight for three different densities. In no case does the error exceed 1%.



Solid line :- Average specific gravity = 0·716
Dotted line :- Average specific gravity = 0·765
Chain-dotted line :- Average specific gravity = 0·816

JFH AUTOMATIC MASS FLOWMETER

Determination of densities

This accuracy can be obtained manually or automatically for measurements of any fluids you may be using in your industry. Consult us:

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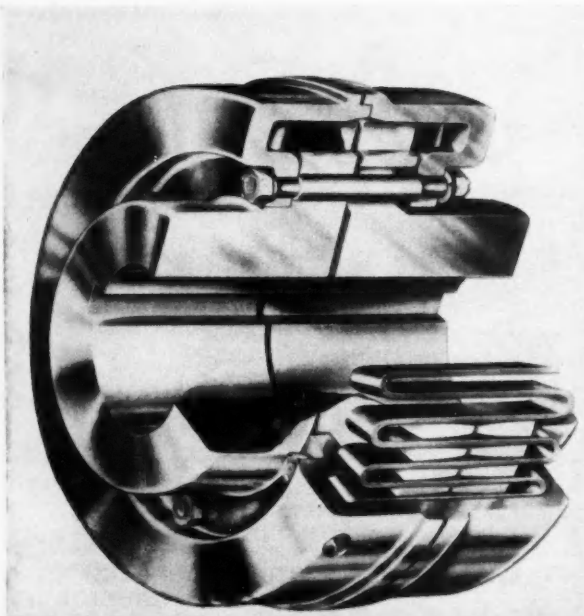

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World famous for outstanding performance and reliability. Made in a wide range of types, all employing the same basic principle of Bibby design.

Special types include: Brakewheel, Cardan Shaft, Turbine, Shear pin, Controlled Torque, Spacer and others.

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Vertical or horizontal
streamlined or functional
THE INCREDIBLY
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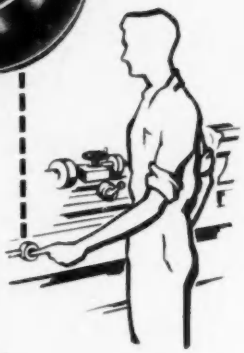

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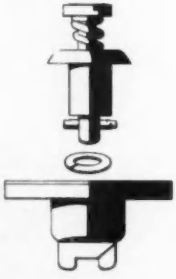

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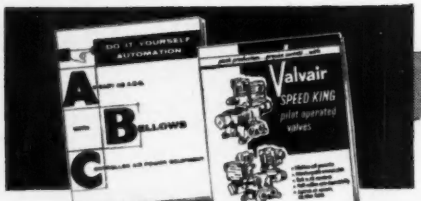

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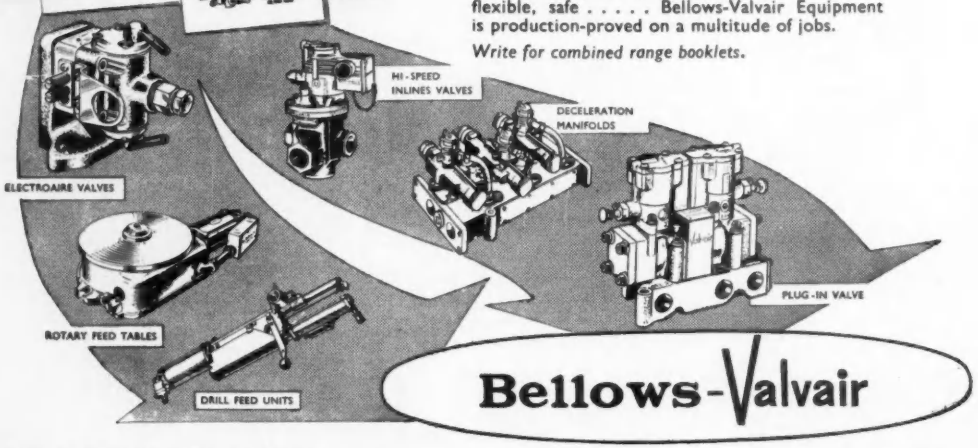

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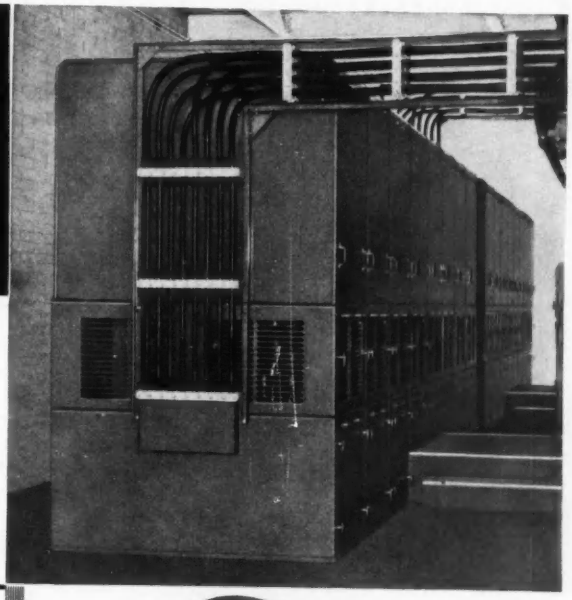

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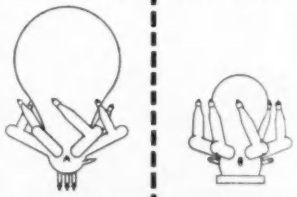

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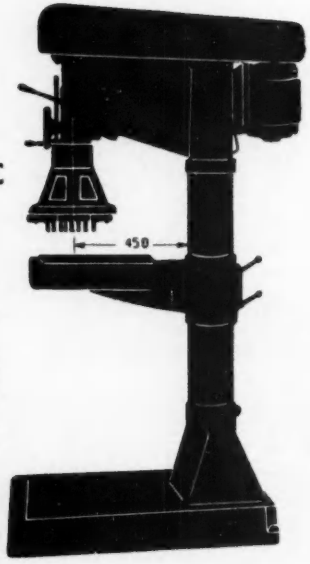

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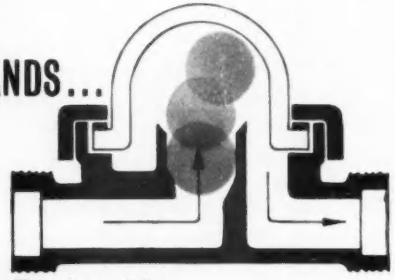

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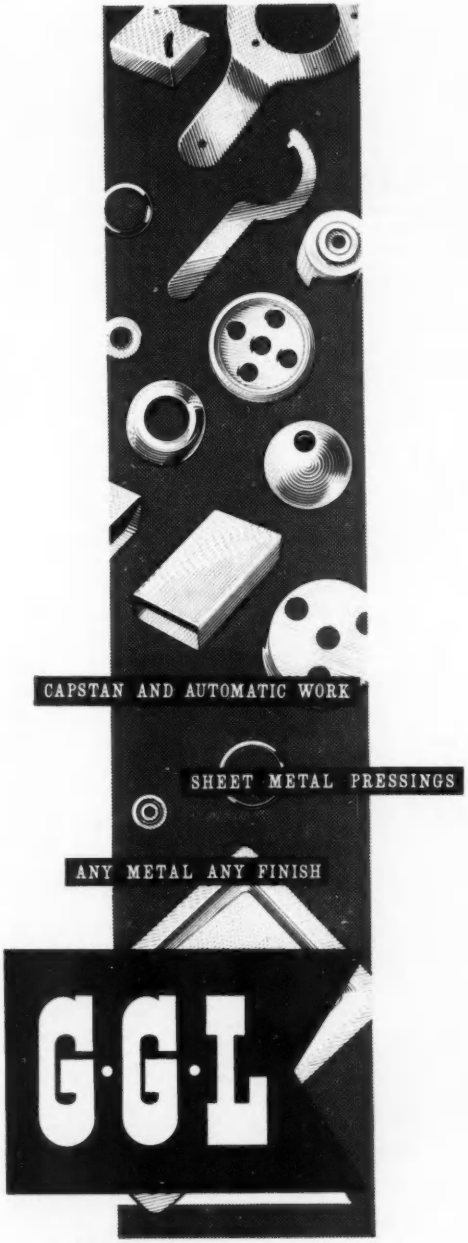

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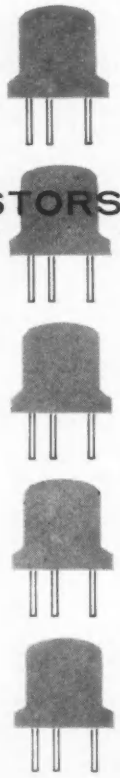

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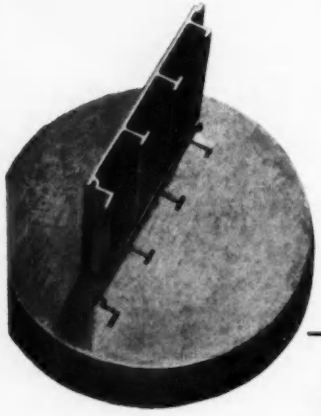

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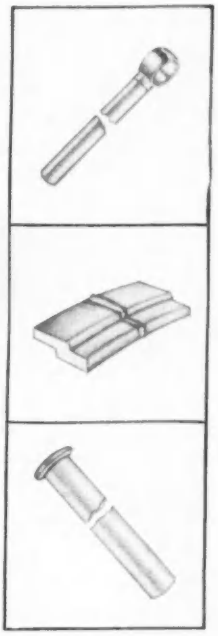

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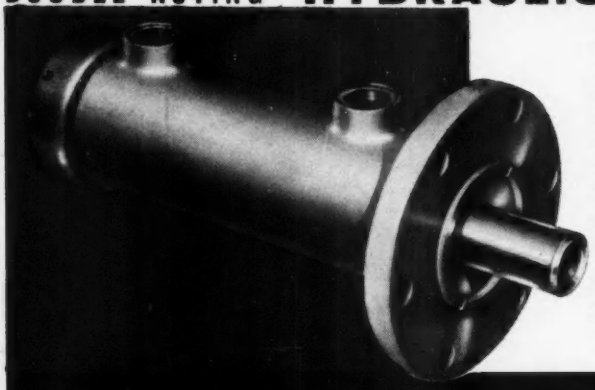

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1000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
½"	1 1/16"	1"	1⅜"	1⅜"	1 11/16"	2"	2"	2⅜"	2½"	3½"	4"
·7854 □"	1·7671 □"	3·142 □"	3·142 □"	5·94 □"	5·94 □"	8·296 □"	12·57 □"	12·57 □"	19·64 □"	28·27 □"	44·179 □"
·1964 □"	·8866 □"	·785 □"	1·49 □"	1·49 □"	2·948 □"	3·142 □"	3·142 □"	6·492 □"	4·908 □"	8·296 □"	12·566 □"
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